ANALYSIS OF DEPARTMENT OF DEFENSE ORGANIC DEPOT MAINTENANCE CAPACITY MANAGEMENT AND FACILITY UTILIZATION FACTORS

THESIS

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AFIT/GLM/LSM/91S-14

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ANALYSIS OF DEPARTMENT OF DEFENSE
ORGANIC DEPOT MAINTENANCE
CAPACITY MANAGEMENT
AND
FACILITY UTILIZATION FACTORS

THESIS

Presented to the Faculty of the School of Systems and
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Master of Science in Logistics Management

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Preface

This research describes capacity measurement and capacity utilization within the Department of Defense to determine whether a single utilization rate should be specified. Simulation models were developed and information about current practices was gathered.

I am indebted to many people for their help in developing this thesis. The JDMAG posture planning staff, especially Mr. Thomas Gorman, took time to provide insights and encouragement. Mr. John Nehring and Mr. William Sullivan at the Norfolk Naval Aviation depot took time from their busy schedules to provide background information about the Navy's approach to capacity measurement. Additionally, the people at HQ AFLC/LGPW were always ready to act as a sounding board and to provide advice.

I want to express special appreciation to my advisor, Lt Col Richard Moore for his unwavering belief in me and for his patience and encouragement.

Finally, I want to thank my family and friends for their love, support and encouragement; for standing behind me when the road seemed all uphill and my resolve ebbed.

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Abstract

This study investigated the effects of mandated depot capacity utilization rates on throughput, inventory, and operating expense. The measures of merit analyzed were work in process inventories, leadtime, and throughput. Since the services do not use a common computer system to track/compute capacity data, computer simulation provided the data used to meet research objectives. The simulation modeled a serially interdependent system subject to statistical fluctuations. Variability in the system was reduced by reducing the spread around the processing time mean. Additionally, buffer inventories were placed in front of each process to protect the process from variability. Constrained systems were buffered and the results analyzed. The final simulation created was a system (drum-buffer-rope) where the input was tied to the constraint output. It was concluded that utilization rates do not reflect process effectiveness nor do they provide information on the level of customer satisfaction achieved. Additionally, this study researched the terminology and methodology used to compute capacity and it was concluded that specific and explicit terminology and methodology must be used to reduce confusion among data users. The study resulted in the recommendation that DOD policy address effectiveness, not utilization and

that performance measures based on throughput, inventory, and operating expense be used to evaluate process effectiveness.

An Analysis of Department of Defense Organic Depot Maintenance Capacity Management and Facility Utilization Factors

I. Introduction

As budgets are being reduced dramatically, capacity management has become an increasingly important topic in the Department of Defense depot maintenance organizations. This chapter describes the background of the research problem and outlines the research goals and objectives. Also included are the scope and limitations of this study as well as definitions of frequently used terms.

Background

For years Congress has believed excess capacity exists in DOD depot maintenance facilities. Current regulations and policies governing depot maintenance require peacetime capacity utilization rates of 100% by 1993 (Atwood, 1990). However, ambiguities in defining and measuring capacity, utilization, and effectiveness of depot maintenance resources have complicated the services' strategic planning for weapon system maintenance and support. Several special studies (GAO,1978; Pyles, 1987) have been conducted to analyze capacity measurement methodology and/or determine the existence of excess capacity and its effect on maintenance efficiency. However, empirical research to determine the potential benefits of alternate measurement methods such as those being adopted by the private sector, have not been undertaken (Fare, 1989; Greer, 1986; Lieberman, 1989; Segerson, 1990). DOD is moving toward aligning depot management with private sector practices (McMillan, 1990). Meanwhile however, private industry is beginning to recognize the capacity and utilization rates not as performance measurements but instead as by-products of the production process. The unquestioning imposition of high utilization rates at a macro level is ill-advised and has the potential of creating problems for the services in meeting mission requirements.

Specific Problem

Current private sector business practices are beginning to challenge the use of specific capacity/facility utilization rates as a measure of performance (Johannson, 1990). The replacement of capacity and utilization rates with measures introduced by Goldratt (1986) (throughput, inventory, operating expense) offers the opportunity to be more effective when allocating and using resources to meet depot maintenance requirements.

Current DOD capacity measures do not differentiate among the different kinds of capacity. As the Ad Hoc Study Team for Capacity/Utilization Measurement Improvement reported, underutilized capacity may be mandated by military necessity such as the need for organic depots, mobilization, national emergencies, unfunded or unforecasted requirements, or Foreign Military Sales (Joint Policy...Study Team, 1990).

Since reserve capacity is not separately identified, current capacity measurement overstates capacity. As a result, utilization rates appear lower than they really are. Thus, a thorough analysis of current capacity measurement and facility utilization requirements, measurement standards, and the appropriateness of the application of a single "ideal" or "optimal" utilization rate at a macro level would be extremely valuable. With a better understanding of capacity-related issues, DOD managers will have the information necessary to make informed decisions relative to day-to-day workloading as well as strategic planning.

Research Objectives

The current state of transition within the DOD community, aligning depot maintenance with the private sector, opens a window of opportunity to assess the appropriateness of criteria and performance measurements used to develop and implement policies and directions. The question to be asked is whether or not ". . . one hundred percent utilization of depot capacity violates both "doing it right" and "doing the right things" (Gartman, 1990). This study will:

1. Determine effects of current mandated depot utilization rates on the logistics pipeline;

2. Evaluate methods of measuring capacity and utilization to determine their relevance in workloading and resource utilization decisions;

3. Determine whether or not aggregated capacity and utilization data provide useful information or whether or not the relevance of the data is diluted through aggregation efforts.

Scope and Limitations of Research

Although this research will determine if there is an ideal aggregated (macro) utilization rate universally applicable to maintenance depots, it will not attempt to determine ideal process level utilization rates for specific workcenters within specific depots. Utilization rates are by-products of the production process, and should not be used .s a primary measure of the success of the process.

Since the services have used differing methods in determining appropriate capacity levels, direct comparisons of raw data cannot be made. To counter the problem of data incompability, the data used in this study will be computer generated, based on a generic model developed to simulate process flows.

Definition of Terms

Capacity: 1) In a general sense, refers to an aggregated volume of work load. 2) The highest reasonable output rate which can be achieved with the current product specifications, product mix, work force, plant, and equipment (APICS Dictionary, 1987).

Capacity Management: The function of establishing, measuring, monitoring, and adjusting limits or levels of capacity in order to execute all manufacturing schedules, i.e., production plan, master production schedule, material requirements plan, and dispatch list (APICS Dictionary, 1987).

Efficiency: Standard hours earned divided by actual hours worked. Efficiency is a measure of how closely predetermined standards are achieved. Efficiency for a given period of time can be calculated for a machine, an employee, a group of machines, a department, etc. (APICS Dictionary, 1987).

Excess Capacity: Capacity for which no current or future requirement exists (Joint Policy...Study Team, 1990).

Inventory: Items which are in a stocking location or work in process and which serve to decouple successive operations in the process of manufacturing a product and distributing it to the consumer. Inventories may consist of finished goods ready for sale; parts or intermediate items; work in process; or raw materials (APICS Dictionary, 1987). In contrast, inventory is defined by Goldratt (1986) as all the money the system invests in purchasing things the system intends to sell.

Operating Expense: All the money the system spends in turning inventory into throughput (Goldratt, 1986).

Peacetime Workloading Capacity: The amount of workload, expressed in Direct Production Actual Hours (DPAH), that a facility can effectively produce considering the management limitations upon applying sufficient workers to continuously fill every work position on a single-shift, 5-day, 40-hour week basis while producing the product mix that the shop is designed to accommodate (DODI 4151.15H).

Physical Capacity: The amount of workload, expressed in DPAHs, that a facility can accommodate with all work positions manned on a single-shift, 5-day, 40-hour week basis while producing the product mix that the facility is designed to accommodate (DODI 4151.15H).

Pipeline Stock: Inventory to fill the transportation network and the distribution system including the flow through intermediate stocking points. The flow time through the pipeline has a major effect of the amount of inventory required in the pipeline. Time factors involve order transmission, order processing, shipping, transportation, receiving, stocking, review time, etc. (APICS Dictionary, 1987).

Product Mix: The proportion of individual products that make up the total production and/or sales volume. Changes in the product mix can mean drastic changes in the manufacturing requirements for certain types of labor and material (APICS Dictionary, 1987).

Reserve Capacity: Capacity which is not fully utilized but must be retained for reasons of military necessity and sound business practice (Joint Policy...Study Team, 1990).

Simulation: The technique of utilizing representative or artificial data to reproduce in a model various conditions that are likely to occur in the actual performance of a system. Frequently used to test the behavior of a system under different operating policies (APICS Dictionary, 1987).

Throughput: The rate at which the system generates money through sales (Goldratt, 1986).

Utilization: A measure of how intensively a resource is being used. It is the ratio of direct time charged for production activities (setup and/or run) to the clock time scheduled for those production activities for a given period of time (APICS Dictionary, 1987).

II. Literature Review

Topic Statement and Justification of the Search and Review

This literature review examines the topics of capacity measurement and facility utilization and the use of these measures in management decision-making relative to resource utilization within the DOD organic depot maintenance environment. In particular, empirical study results applicable to the question of ideal utilization rates are discussed.

Scope of the Research Topic

The literature reviewed for this study is grouped into several areas: (1) historical review of capacity and facility utilization reports and studies, (2) regulations applicable to capacity measurement and facility utilization, (3) current capacity-related study reports, (4) emerging management philosophies, (5) simulation and modeling philosophies and techniques. These areas are all necessary to understand capacity measurement and facility utilization issues.

1. Historical Review. A common thread throughout the early literature is the theme that existing capacity measurement criteria have failed to provide management with useful information for developing maintenance management policies and making decisions (Johansson, 1990; Nelson,

1989). Varying capacity measurement criteria among the services invalidate any direct comparison of capacity measures among the services (Pyles Study, 1987). Independent empirical research studies supporting use of current capacity measurement procedures are lacking. Nevertheless, in the absence of empirical evidence to the contrary, existing policy and regulations specify development of measurement criteria and utilization rate (DODI 4151.1, 1976).

2. Regulations. DOD regulations governing capacity and facility utilization have remained unchanged since 1976. Despite the fact that all services operate under the same regulations, interpretation has varied widely. The methodology for measuring capacity is defined; however, facility utilization computation is not. Although the process for determining capacity is spelled out, the methodology whereby the individual factors are calculated is not prescribed precisely. Each service has calculated direct labor based on different assumptions; the Air Force based their computations on 2000 hours, the Army used 1656 hours as a base. Meanwhile, Naval Air Systems Command adopted the Capital Assets Planning and Management System (CAPMS) in lieu of using DODI 4151.15H. Facility utilization rate computation is not explicitly defined; it is merely identified as a ratio of input and output (DODI 4151.1).

3. Current Capacity Study Reports. Reports of current capacity and facility utilization studies are limited. A common thread throughout capacity related literature is the theme that existing capacity definitions, at best, represent a complex concept not readily understood by business managers. Alan Greenspan, Chairman of the Board of Governors of the Federal Reserve Board, in recent testimony before Congress, stated that "capacity is a somewhat elusive concept" and confirmed that he uses capacity utilization as one of the data elements for judging the degree of tightness of the economy (Shapiro, 1989). Private industry appears to continue to address capacity and utilization through default.

Although the term "capacity utilization" appears in industrial organizational literature, there is little consensus as to the proper way of defining and measuring capacity utilization (Nelson, 1989). Approaches to capacity and utilization measurement appear to be either engineering or economic, with each approach altering the perspective and data represented.

The engineering approach toward capacity utilization views potential output as a representation of the maximum output that may be produced given a firm's short-run capital. The economic approach, also centered around potential output, is conditioned by economic circumstances and must be interpreted as being the optimum output from the economic point of view. Potential output espoused in the economic approach is defined as that output at which the long-run and short-run average total cost curves are tangent or that output at which the short-run average total cost curve reaches its minimum (Nelson, 1989).

Implicit in the conceptual engineering definition of capacity is the assumption that some factors of production are fixed in the short-run. The economic definition of capacity appropriate for the firm (maintenance depot) is a cost-minimizing approach; a level of output high enough that fixed factors are not idle, but not so high that variable factors are making the marginal cost curve very steep (Shapiro, 1989).

The Federal Reserve defines capacity utilization as the ratio of actual production to capacity, but does not define capacity. To take into account seasonal fluctuations, the Federal Reserve smooths capacity data while assuming capacity and production have the same seasonality patterns (Esposito, 1986). The Bureau of Census publishes two utilization rates: the preferred utilization rate and the practical utilization rate. The practical rate is the ratio of actual operations to practical capacity where practical capacity is defined as the greatest output which a plant could produce using realistic work patterns. Preferred capacity is that output level which a manufacturer would prefer not to exceed because of costs or other considerations (Esposito, 1986).

The private sector continues to focus on selecting production capacity to meet profit maximization objectives. In contrast, the military emphasis remains on achieving maximum facility capacity/utilization (in an attempt to achieve cost minimization goals). Sometimes this is at the expense of key measures of effectiveness such as throughput, inventory, and operating expense.

The Ad Hoc Initiative to Improve Capacity Measurement study report released in November 1990 states:

> There is a prominent school of thought within the academic community that argues that targeting 100 percent utilization is usually a costly approach. Rather than matching workload with capacity, facilities can operate at a more cost effective level by balancing flow with demand. Total Quality Management approaches accept less-than-full capacity scheduling, since it allows for emphasis on cost, quality, and schedule.
>
> Based on this reasoning, it is recommended that the DOD utilization policy in DODI 4151.1 be revised to recognize the need for reserve capacity and require a level of peacetime utilization that will ensure that mobilization and contingency requirements can be met while operating in a cost effective manner.

While the 100 percent utilization rate mandated by current policy is being challenged, no alternatives have been offered nor has an acceptable level of utilization been proposed. Related industry reported capacity utilization rates during 1989 and 1990 are: modern material handling, 82%; general industrial, 82%; mining, 87%; primary processing (materials and supplies), 89%; and advanced processing (finished consumer, capital goods), 83.4% (Feare, 1990; Ellis, 1990; and Raddock, 1990).

4. Emerging Management Philosophies. Production and manufacturing management philosophies are shifting away from using capacity and utilization factors as performance measurements on which policy and decisions are made. "Utilization has never made sense as a measure of management performance. Yet it has come to be used that way, and that leads to bad decisions" (Schonberger, 1986, p.4).

The Japanese approach to workloading and production, Just-in-Time (JIT), is based on the premise of meeting customer requirements with a high quality product in a timely manner at the lowest cost. Full-capacity loading/utilization is not considered a performance measure. Instead, workers are encouraged to use idle time to find solutions to problems and to help out in bottleneck areas. Full capacity loading is considered detrimental to achieving the goal of continuous improvement (Schonberger, 1982).

Theory of Constraints (TOC) philosophy maintains that three measures (throughput, inventory, operating expense) are the only relevant measures to be considered. Goldratt (1990) purports that the traditional approach of balancing workload with capacity is inappropriate; the best way to achieve the profit maximization goal is to balance process flow with demand. Statistical fluctuations (variations) cannot be averaged out; effects of fluctuations are additive and time lost at a bottleneck cannot be recovered. Constraint management is the means used to achieve process balance. Bottlenecks are loaded to 100 percent of their capacity while remaining resources are loaded to the levels required to maintain an even flow through the system without creating excess inventory along the way. In a production/manufacturing facility, where statistical deviations occur, or where unanticipated/unscheduled disruptions strike, scheduled protective inventory in front of a bottleneck buffers the critical resource and protects against disruption of the system. This approach optimizes facility utilization by decreasing operating expenses and inventory while increasing throughput (Goldratt and Fox, 1984; Lundrigan and Borchert, 1988). Equipment and facility utilization and activation are not synonymous; utilization means that the output is meeting a current demand or requirement while activation means that the output is being produced merely to keep the equipment and facility operational. Although activation provides high efficiencies (ratio of on time and available time) the resultant output may not add to the firm's bottom line--profitability.

Aggregation of capacity data, even when translated into a common measurement such as Direct Labor Actual Hours, is misleading. It would seem comparisons between different work centers working divergent product mixes can be drawn since the data are presented in similar terms. For example, one hour of sheet metal capacity cannot be substituted for one hour of electronic repair capacity. Capacities of work centers producing different products (e.g. flight control instruments for advanced fighter vs structural repair on aging transport planes) are not easily compared; the use of a "common denominator" masks disparity between the nature of the work performed even though it is a commonly accepted approach (Blackstone, 1989).

5. Simulation and Modeling. Because experimenting with capacity measurement and facility utilization data systems already in place within DOD is neither practical nor possible, computer simulation provides a means for empirically testing the hypothesis that an ideal utilization rate exists. Simulation allows researchers to make inferences about system behavior by changing various process parameters, and observing the results, and to make inferences about system behavior. Cook and Russell's (1989) approach to simulation provided the starting point for preliminary simulation considerations. Developing the simulation study included problem formulation, data analysis, model formulation (figurative and mathematical), program generation, validation/verification, and experimental design.

Discussion

Although capacity measurement and facility utilization within DOD have been continuing topics of discussion, empirical studies have not been undertaken to validate the assumptions underlying management's proposed policies. Determining whether or not the use of existing capacity and utilization data are appropriate performance measurements has not been accomplished. Although the use of DLAHs provides a common parameter, can the assumption be made that all DLAHs are equal or comparable? If not, then how are workloading and resource decisions impacted by aggregate figures?

Recently published industrial production texts indicate overemphasis on maintaining high production efficiencies will reduce throughput (output that can be sold) and increase inventory (Chase and Acquilano, 1990). The impact of increased inventory levels, reduced competitive edge, is observable in price structure, product, and system responsiveness. Products held in inventory (both work in process and finished goods waiting to be sold) must be reworked or scrapped whenever engineering changes or quality problems arise. Operating costs increase, throughput decreases. Excess inventory levels lead to lower prices and higher margins which reduce bottom line profitability. As inventory levels rise, increased lead times and delayed deliveries reduce competitive edge and escalate operating expenses. The effect of increased inventory and operating expense moves the company off the minimum cost point on the cost curve. Resource allocation is not optimized. Ultimately, the question of performance measurements is tied to the question "What is the real goal of the company?" As pointed out in The Goal,

> if low-cost production is essential, then efficiency would seem to be the answer...Producing a quality product efficiently: that must be the goal...It's not enough to turn out a quality product on an efficient basis. The goal has to be something else...The company exists to make money (Goldratt and Cox, 1986, p. 38-40).

Although the goal of DOD is not to make money but to provide a given level of service at minimum cost, the principles applied to private sector business would appear to be appropriate especially in maintenance processes that are common to both sectors. Goldratt emphasizes the total system. Throughout all of his writings, the system goal is the bottom line. As he states in Theory of Constraints:

> Thus, every action taken by any organ--any part of the organization--should be judged by its impact on the overall purpose. This immediately implies that, before we can deal with the improvement of any system, we must first define the system's global goal; and the measurements that will enable us to judge the impact of any subsystem and any local decision, on this global goal (p.4).

Should measurements taken at a local level be used to judge the impact on the system at the global level? This study attempts to determine the applicability of basing macro level decisions on aggregated micro-level data. Goldratt's admonition found in The Haystack Syndrome:

> Theory of Constraints hammers over and over again: "Local optima do not add up to the optimum of the total." Total Quality Management reminds us that: "It is not enough to do things right. What is more important is to do the right things." And Just-In-Time puts on its flag: "Do not do what is not needed." (p.51)

This statement reminds us that basic shifts in management philosophy are required to answer the tough questions faced in today's environment.

Summary

The question of the use of capacity measurement and facility utilization data as performance measures has been periodically debated. It remains to be established whether or not an ideal utilization rate can be universally applied to depot maintenance facilities. Workload consolidation decisions being made in this day of declining forces, weapon system inventories, and changing political environments should be based on relevant data. Information used by decision-makers should be based on empirical data demonstrated to be significant as opposed to data gathered to meet externally-imposed criteria.

The 100 percent utilization mandate, ignoring the impact of policies on the system as a whole has the potential of leading the depot system into a downward spiral. Eventually, due in large part to inappropriately focused priorities, the depot system has the potential of becoming even more uncompetitive. This research will test the recently-directed utilization policy on a simple system to determine its impact and feasibility on even simple systems. Only after this policy has been demonstrated to be effective on simple systems should it be applied to the infinitely more complex systems of the maintenance depots.

III. Methodology

Introduction

This chapter describes and discusses the methodology employed to address the research problem and objectives. As stated in Chapter 1, the hypothesis to be tested is that there is a single facility utilization rate which is universally applicable. The alternate hypothesis states that there is no single utilization rate which should be applied to all resources. The alternate hypothesis would lead to the conclusion that utilization rates should be viewed as by-products of strategic business decisions driven by corporate goals and market demand. The remainder of this chapter details the simulation methodology and describes the systems used to test the hypotheses outlined in Chapter I.

Description of the Data Section

In the hard sciences, such as physics, "thinking" or "gedanken" experiments are used to illustrate concepts without the need to explicitly carry out the experiment. The characteristics of the situation under consideration can be simulated or modeled; variables can be controlled and manipulated to determine the effects of changes in the inputs or the system. Measures of merit are established and outcomes are analyzed to determine the impact and significance of the changes.

Current capacity and utilization policy appears to be based on the theory that maximum utilization is synonymous with maximum effectiveness (Atwood, 1990). Because of the shrinking DOD budget and the changing global political environment, the policies and decisions affecting depot maintenance workloads and facilities should be based on performance measurements that are relevant. Simulation-based research was chosen to assess and evaluate the principal objective of determining the effect of mandated utilization rates on the logistics pipeline.

Experimentation with existing DOD systems was impractical; therefore, a "gedanken" experiment was performed to provide a simple tool for analysis and to explore concepts relevant to capacity and utilization. Computer modeling provided the vehicle to accomplish the experiment.

1. Simulation Development. The simulation was developed in GPSS/H, personal version 2.0 and was run on an IBM 286 turbo computer with a 40MB hard drive and 347K extended memory. Although the simulation model was originally patterned after the dice game in Goldratt's The Goal, (pages 102 - 111), using a uniform distribution with range of 1 - 6 and mean of 3.5 processing time overloaded the common storage limits of GPSSH due to the number of transactions generated. To reduce the number of transactions created, the range was changed to 5 - 30 with a mean of 17.5.

BASELINE MODEL. The BASELINE simulation model represents a serially-dependent, balanced, single server, five-step process subject to statistical fluctuations (Figure 1). Queues were allowed to grow infinitely (within the limits of GPSSH). Model execution was accomplished through the use of nested DO loops within the program (Appendix A). The program generated transactions during 100 time periods in each run. System initialization is based on 50 repetitions of the 100 time units for a total of 5000 time units. The system is then RESET, with statistics zeroed but transactions left in the system queues and servers. The second and third DO commands in the program control the length of the run wherein statistics are collected. The system is run for another 2500 time units during which statistics are gathered. The CLEAR command succeeding the ENDDOs, zeroed the statistics and transactions prior to invocation of the first DO command. The first DO command created thirty replications of the model run.

The BASELINE simulation model was created to provide maximum flexibility for changing input parameters. Soft-coded variables were used instead of hard-coding the data. This flexibility enabled the user to customize the model: to change it from single to multiple servers; to unbalance the line; or to change the length of the run.

The BASELINE model assumed an infinite input pool.

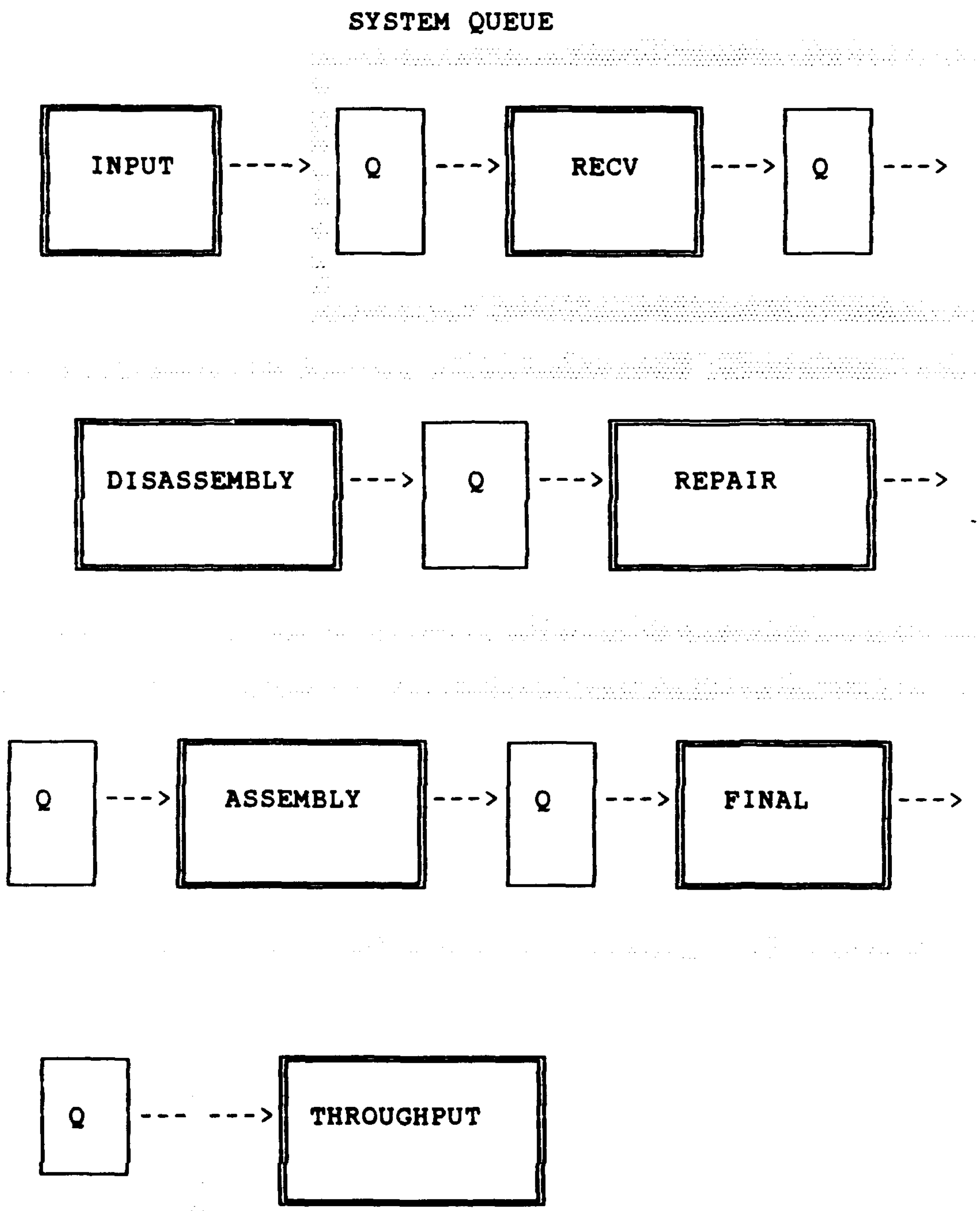

Figure 1. BASELINE Simulation Model

Transactions generated every 17.5 +/- 12.5 time units according to a uniform distribution entered the system queue. Transactions waited in line to enter the first process (RECV) queue. Transactions were then processed on a First In First Out (FIFO) basis throughout the system. Queues in front of each process represented work in process (WIP) inventories. Transactions sat in the queue until the server became available. When the server became available (after the transaction had left to move on through the system) a transaction was allowed to enter the server. The transaction resided in the server for 17.5 +/- 12.5 time units. At the end of that time, the transaction left the server and entered the next queue. The transaction waited its turn in the next queue until the next server became available. The same procedure was followed for all five steps in the model. After a transaction left the FINL process, it departed the system queue before it was terminated. Since this model assumes no market constraints (i.e. output = throughput) terminated transactions represented throughput.

Transactions entered the system every 17.5 +/- 12.5 time units. If transactions did not have to wait in queues, the expected flow time was 17.5 x 5 = 87.5 time units. The expected output rate was 2500/17.5 = 142.857 transactions per run. Each server could process only a single asset at a time, therefore the longer the process time, the greater the number of units that backed up in the queues. By the same token, the shorter the process time, the shorter the queue. The RECV process was dependent on the system arrival rate. The DASM queue size was dependent on the RECV process time for its input and dependent on the DASM process for its output. This dependency was repeated throughout the system, thus system flow time was dependent on the processing time fluctuations within the system. Actual throughput values were compared to expected values in computing sample statistics.

BUFFERED BASELINE MODEL. To determine the system impacts of protecting the system from statistical fluctuations two different methods were used. In the first model modification, buffers were placed in front of each of the steps in the process (Figure 2). Transactions were generated at 17.5 +/- 12.5 time units and entered the system queue and were processed on a FIFO basis. Transactions could not leave the process "ADVANCE" block until the buffer block had available capacity (storage). Transactions staying in the "ADVANCE" block prevented entrance by younger transactions. This transaction behavior was repeated throughout the system. Transactions had to leave the system queue before being terminated and counted as throughput.

REDUCED VARIABILITY MODEL. An alternate method used to reduce the effects of statistical fluctuations was thereduction of variability within the process. The variability reduction was accomplished by decreasing the

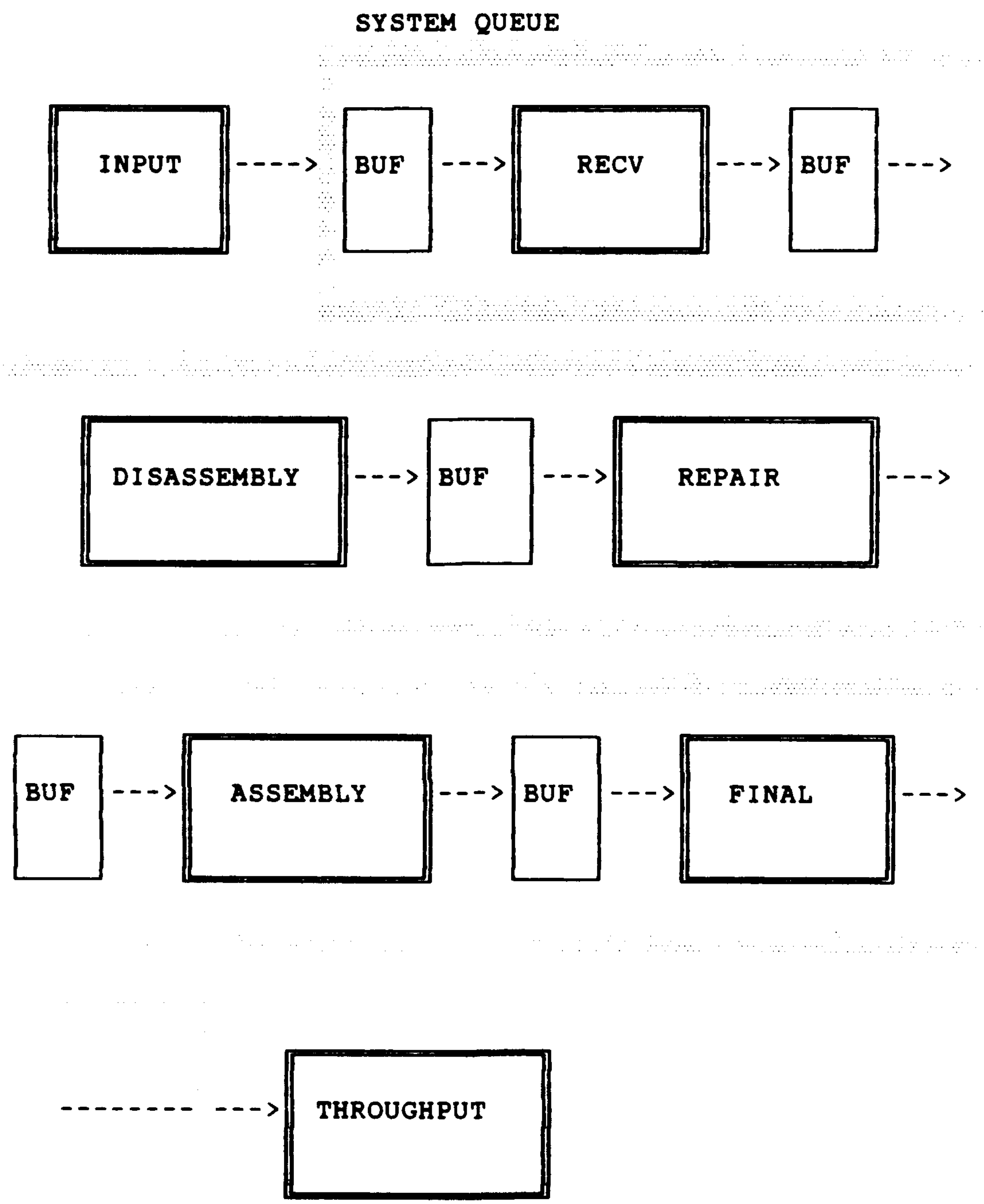

Figure 2. BUFFERED BASELINE Simulation Model

variability around the mean (Appendix A). The first variability adaptation of the BASELINE model was created by reducing the generation and process spreads from 12.5 to 7.5. The second variability adaptation was accomplished by reducing the spread to 2.5. The model configuration remained unchanged from the BASELINE model. The measures of merit under consideration included throughput, queue sizes (WIP), and the time/unit in the system. Expected values were compared to actual values in computing sample statistics.

CONSTRAINED MODEL. To unbalance the system, a constraint was coded into the model (Appendix A). Other than the change in process time, the process flow remained the same as the BASELINE model (Figure 1). The independent variables subject to changes from the baseline model were the process time mean and spread, and the server capacity. Changes of any one or any combination of these variables were used to create a constraint within the system. Program codes are included in Appendix B. The CONSTRAINED BASELINE model included infinite queues between the processes. Transactions were generated every 17.5 +/- 12.5 time units and enter the system queue. The transactions resided in the leave block until the next process (server) became available. Waiting transaction queues built up in the leave block; transaction processing continued while queues built up.

<u>DRUM-BUFFER-ROPE MODEL.</u> The DRUM-BUFFER-ROPE model (Figure 3) was programmed to tie transaction entries into the system to the constraint output. Even though transactions were generated every 17.5 +/- 12.5 time units, transactions were barred from entry into the system unless the coded gate preceded by the generate statement was opened by the logic switch coded into the model. To prime the system, three transactions were generated, allowed to enter the system queue, and were unconditionally transferred to the RECVQ. Without priming the system, the gate remained closed. Expected values and actual values were compared for computing sample statistics.

<u>Measures of Performance.</u> Throughput (the number of transactions passed through the system), average queue contents (work in process inventory), and the time/unit (flow time) in the system were the relevant measures. Server utilization rates were also tracked. Operating costs were not separately computed but were assumed to be related to inventory costs. As inventory levels rose, it is expected that the portion of OE related to inventory would rise proportionally.

<u>Assumptions.</u> The simulation model assumed a pure environment; the real world scenario operates within fiscal and policy limitations, i.e. batch and on demand inductions, workload renegotiations, mandated utilization rates, variances in the process. The type of policy constraint in

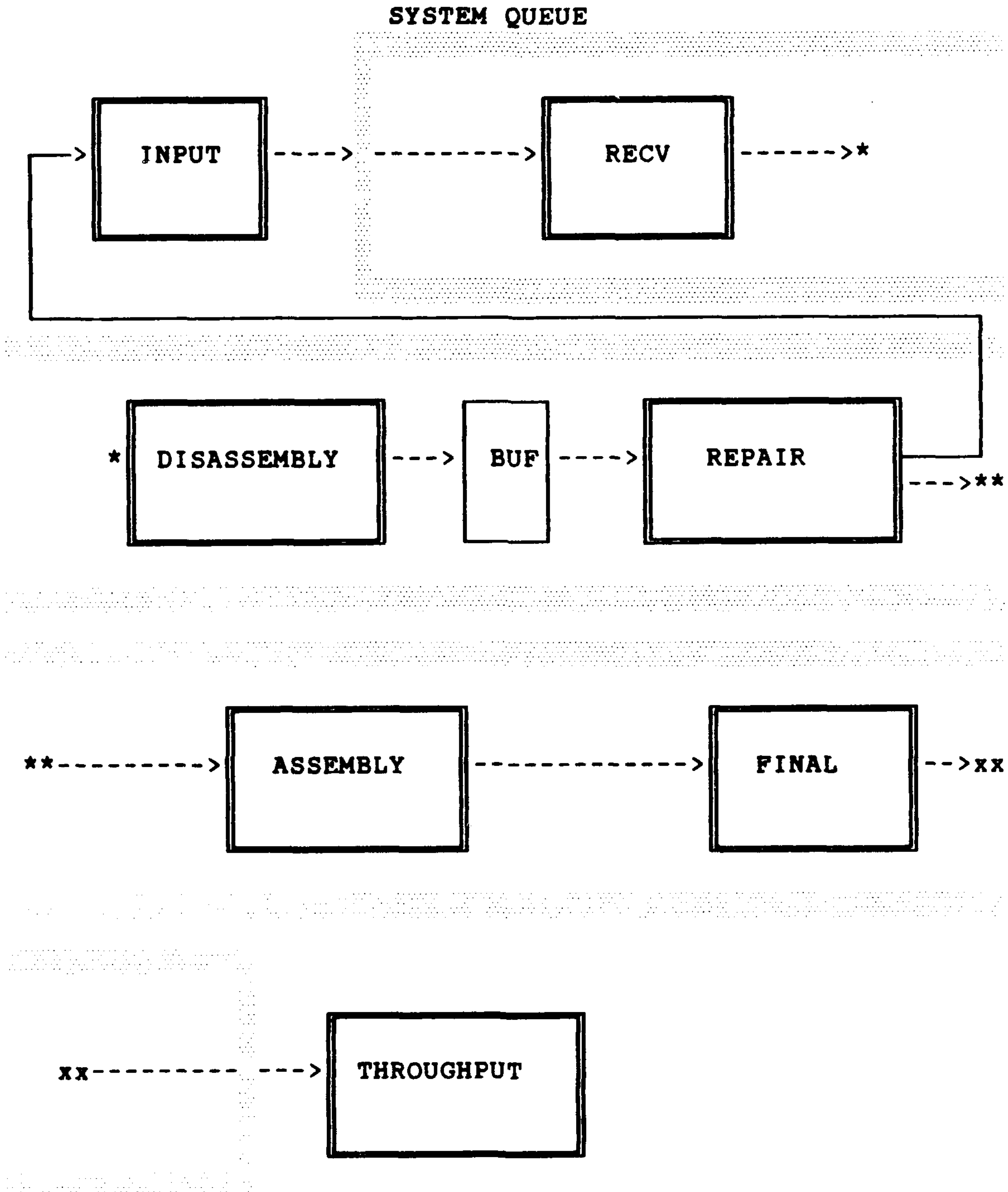

Figure 3. Drum-Buffer-Rope Simulation Model

a system determines both throughput and inventory (Goldratt, 1990). Assumptions underlying the model development also included:

> the process was continuous;
>
> throughput was equal to demand;
>
> interarrival times and process times were uniformly distributed;
>
> First In First Out (FIFO) processing for all queues.

2. Justification. Experimentation with existing DOD systems was impractical. Since the services do not use a common computer system to track/compute capacity data collection is limited by fragmented files and incompatible formats.. The service systems are large, not interactive, and not set up with a "what if" capability. Process simulation provided the data required to meet the research objective of determining the effects of utilization rates on the logistics pipeline while laying the groundwork for examining the remaining objectives. Simulation also allowed establishment of a common base across the services since capacity measurement currently varies among services. The simulation provided consistent output patterns for the various runs completed.

3. Verification and Validation. Because the simulation was fairly simple and straightforward, informal analysis techniques were used for model verification and validation. Desk-top checking and expert validation and verification

were performed. Logic, consistency and completeness were checked throughout the model development. Independent reviewers also checked the model. To verify that the input parameters read in from an external file were really being processed as expected, those parameters were hard coded into the model and the results were compared. Identical output verified that input parameters were being properly read and processed. Hand calculations were cross checked with simulation results to verify the model performed as expected. Simulation output was also checked to see if it was logical and to determine if it met expectations.

4. Data Generation. Fifty repetitions of the simulation were performed to achieve steady state. Statistics collected for analysis were gathered from repetitions 51 through 75. The relevant measures evaluated were the number of transactions processed through the system (throughput), the average contents of the queues (work in process inventory), the average time a transaction was in the system (flow time/leadtime), and the process utilization rates.

The first run established the BASELINE. To determine whether or not throughput could be improved by reducing the impact of random statistical fluctuations in the process, inventory buffers in front of each step in the process were added in the BUFFERED BASELINE model. The next series of runs were made to determine the effect of reducing the variance of the process. Line "balance" was maintained throughout the above runs.

To unbalance the line, a constraint was introduced into the system. The constraint was created by changing the parameters of the Repair process (Step 3). Two methods were used to create the CONSTRAINT model: 1) increase the mean (increased processing time) of the REPR process; 2) decrease the processing times of the nonconstraints by doubling the capacity. Asset generation rates remained unchanged from the baseline. Again, the relevant measures were collected for analysis.

The BUFFERED CONSTRAINT model included a buffer in front of the constraint while the balance of the line remained unbuffered. The buffer blocked the system from processing when the capacity was full. Throughput, utilization rate, queue length, and flow time statistics were collected.

The final model adaptation created the DRUM-BUFFER-ROPE model. Asset generation was tied to constraint output thereby subordinating the system to the constraint. Relevant measures were taken from the standard GPSSH output. Leadtime (a function of inventory) was computed from model generated data.

<u>Description of the Process Section</u>

In addition to the simulation, this study reviewed capacity and utilization measurement methodology used within DOD and the private sector. Sources of information included available literature, current DOD regulations and proposed regulatory changes. The process section also investigated how the capacity and utilization data is used within DOD and the private sector. In addition to the sources of information used to investigate the methodology, personal conversations provided anecdotal information on data usage.

The DOD capacity measurement methodology was flow charted. The process was examined for inconsistencies and logic flow. Applications (uses) of capacity and utilization data at the different levels of the hierarchy within DOD and the individual services were reviewed and informally categorized as planning inputs or performance measurements. The results are presented in Chapter IV.

IV. Findings and Analyses

This chapter provides the findings and analyses of the data and process sections of the research project. Analysis of the findings are also included.

Data Section

Once the system to be modeled had been established and the processing times and variability for each of the processes determined, the first step was to benchmark the system. One common misconception related to processes that are serially dependent is that the variability will average out over time. A result of this approach is the belief that the average throughput of the system can be calculated by dividing the total run time by the average processing time. Therefore, to benchmark the system for comparative analysis, the measures of merit were calculated assuming fixed mean values for the generation and processing times in the BASELINE model. The expected throughput was computed to be 142.85 units (2500/17.5=142.85).

Expected system flow time/leadtime was computed by multiplying each processing time by the number of processes (17.5*5=87.5). In this simulation all processing times were equal. In the DOD, calculations of capacity fail to consider variability in processing time. Thus the calculations would assume no work in process queues would form and all servers would be utilized 100% of the time.

The results of the simulation runs were compared to the benchmarks and model behaviors were compared to the expected outcomes.

To determine buffer levels, the anticipated generation rate for a single repetition was computed by dividing the run time units by the mean (100/17.5=5.71). Assuming a production cycle is 100 time units, the 5.71 units represent the number of units needed to protect the process from a disruption equal to a single production cycle. This calculation was considered in selecting alternative buffer levels.

Simulation results are summarized in Appendix C and presented graphically in Figure 4.

Finding. Although the BASELINE simulation assumed a balanced process from an industrial engineering perspective, statistical fluctuations and interdependent processes caused all measures of merit to be less than optimal. Server utilization was less than 100%, WIP inventories were higher, leadtimes were longer, and throughput was lower than expected.

The managerial response to degradation of measures in operational environments would be to protect throughput by increasing the levels of protective inventory. This action is simulated by the simulation run titled BUFFERED BASELINE. Three different levels of inventory were used to evaluate the effect of increasing the inventory level on critical measures of merit.

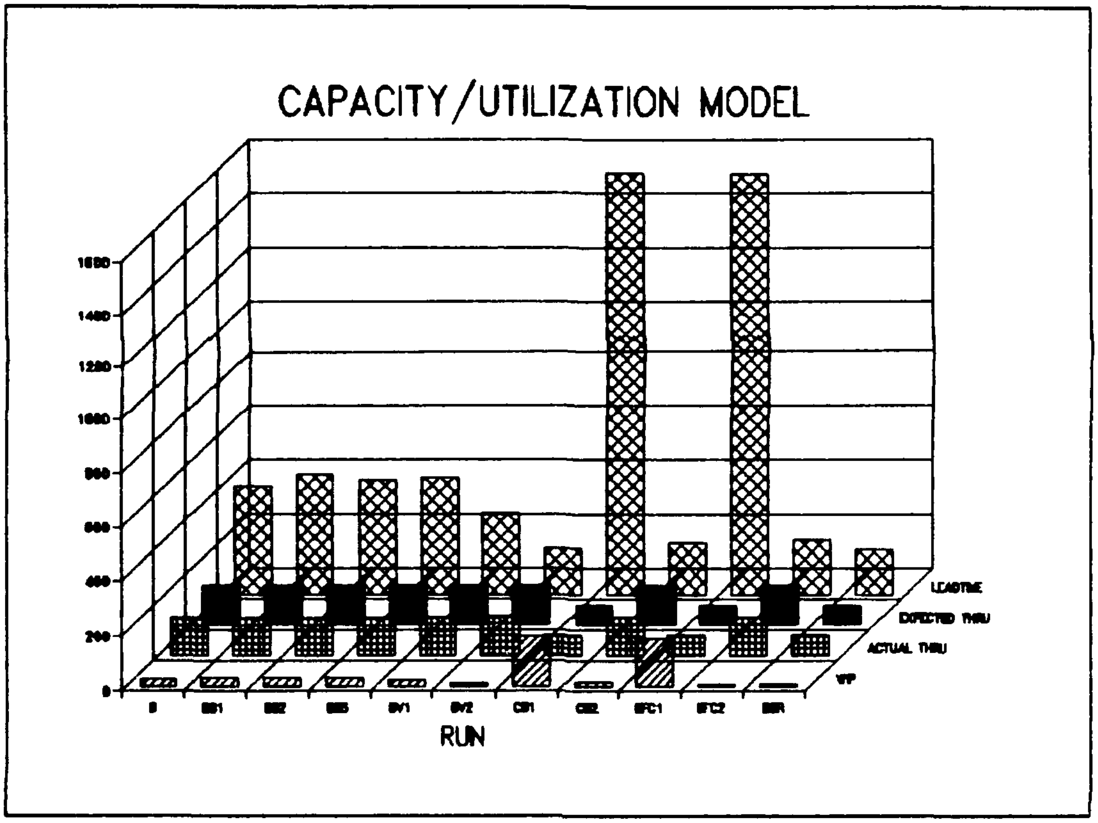

Figure 4. Capacity Utilization Summary Chart

RUN	RUN TYPE		UTILIZATION RATE
B	Baseline		0.9628
BB1	Buffered Baseline	(Buffer 6)	0.9752
BB2	Buffered Baseline	(Buffer 9)	0.9728
BB3	Buffered Baseline	(Buffer 12)	0.9740
BV1	Reduced Variability	(7.5) spread	0.9830
BV2	Reduced Variability	(2.5) spread	0.9952
CB1	Constrained Baseline	(REPR mean 35)	0.7932
CB2	Constrained Baseline	(NC capacity 2)	0.5952
BFC1	Buffered Constrained	(Buffer 6, C1)	0.7918
BFC2	Buffered Constrained	(Buffer 6, C2)	0.6314
DBR	Drum-Buffer-Rope	(Buffer 6)	0.6026

NC = Non-constraint
C1 = CB1
C2 = CB2

To protect the process from the effects of statistical fluctuations and process interdependence, buffers were placed in front of each resource. Buffer levels were established approximately equal to the base disruption production level, one and one-half times the production cycle generation rate, and double the production cycle generation rate (this equates to inventory levels of 6, 9, and 12 units respectively). Comparison of the BUFFERED BASELINE RUNS (BB1 through BB3) to the BASELINE showed that all measures of merit increased slightly (utilization rates, WIP, system leadtime, throughput). However, the resulting changes in the system were not statistically significant at the .05 level ($\alpha = .05$). The effects of adding buffers to the process are as summarized in Table 1.

RUN	B	BB1	BB2	BB3
Throughput	136.07	136.7	137.07	137.40
WIP	26.25	30.3	28.49	29.62
Flow Time	393.497	440.938	420.208	427.445
Utilization	.9630	.9750	.9730	.9740

Table 1. Comparison of BASELINE and BUFFERED BASELINE Results

A second approach to limiting the impact of variability is to take action to make processes more reliable by reducing inherent variability in the system. Total Quality Management and Just-in-Time are both managerial philosophies which advocate variability reduction through ongoing improvement.

In the simulation runs focusing on the impact of variability reduction (BV1 and BV2), this reduction was achieved by reducing processing time spread. The width of the spread ranged from +/- 12.5 (BASELINE) to +/- 2.5 (BV2). BV1 represented the midpoint (+/- 7.5) of the variability range. Reducing processing time variability led to increased throughput levels, decreased inventory, and process times. As variability approached zero, resource utilization rates increased to almost 100 percent. The effects of reduced variability are listed in Table 2.

Variability	B	BV1	BV2
Throughput	136.07	138.6	141.7
WIP	26.25	19.086	10.193
Flow Time	393.497	296.955	167.015
Utilization	.9630	.9830	.9950

Table 2. Effects of Reducing System Variability

Reduction in variability had little effect on the total throughput of the system since each of the systems came within 6 units of achieving the theoretical maximum number of units produced (Table 2). What is significant for these three runs is that the amount of WIP is reduced by over 60 percent compared to the baseline model. This could translate to a significant saving in investment in spares and inventory carrying costs. As a result of the lowered work in process levels, lead time was reduced by nearly 57 percent. In operational terms, the system would be much more responsive to customer requests as a result of the reduced pipeline time.

The first two variations on the model were to buffer against variability with inventory or to attack the sources of the variability. Although variability existed in each of these simulation runs, the models were "balanced" on the basis of average processing time for each of the stations. Unfortunately, in most settings achieving this level of balance is unrealistic. The next five simulation models addressed systems which contained internal resource constraints. A CONSTRAINED BASELINE (CB1) model was run to benchmark the system. The constraint was created by doubling the processing time for the repair (REPR) workstation while leaving all other processing times unchanged. This doubling of processing time naturally reduced the expected throughput to half the level of the unconstrained model.

Table 3 depicts the results of unbalancing the line. System response (as determined by the measures of merit) to increased process time (doubled mean) of the REPR process

(CB1) was more intense than changing the capacity of processes 1, 2, 4, and 5 (CB2). Utilization rates of the RECV and DASM processes are roughly fifty percent when the capacity of these processes is doubled whereas the utilization rates of the processes are nearer to one hundred percent when the REPR process time is doubled (Table 4). The ASSM and FINL process utilization rates remain approximately fifty percent regardless of how the constraint was created. It was no surprise that the REPR process output rate limited the succeeding process utilization rates. When the raw material input rate matched the constraint process time (CB2 and BFC2), the expected throughput remained unchanged. The expected throughput fell to approximately one-half when doubling the constraint mean and leaving the input rate matched to the nonconstraint mean (CB1 and BFC1). Utilization rates of the nonconstraints preceding the constraint vary based on how the constraint is created (CB1 and CB2). Doubling the nonconstraint capacity reduces those processing times in half.

The managerial implications derived from this run are related to the arbitrary use of utilization as a performance measurement for all work stations. For non-constraints in the routing before the constraint, high levels of utilization could be maintained as seen in simulation CB1. Products produced by these work centers piled up in front of the constraint where they only increased WIP and leadtime while making no contribution to overall throughput.

RUN	B	CB1	CB2	BFC1	BFC2
Throughput	136.73	71.97	140.27	71.74	139.700
WIP	26.25	180.31	11.51	176.12	7.176
Flow Time	393.49	1568.68	186.459	1566.92	199.306
Utilization	.9630	.7930	.5950	.7920	.6310

Table 3. Differences Between Baseline and Unbalanced Lines

UTILIZATION RATES						
RUN	RECV	DASM	REPR	ASSM	FINL	AVG
B	.9800	.9660	.9580	.9650	.9450	.9628
BB1	.9980	.9830	.9730	.9680	.9540	.9752
BB2	.9960	.9840	.9670	.9670	.9500	.9728
BB3	.9890	.9850	.9730	.9610	.9620	.9740
BV1	.9940	.9860	.9750	.9810	.9790	.9830
BV2	.9970	.9980	.9950	.9940	.9920	.9952
CB1	.9920	.9750	1.0000	.4980	.5010	.7932
CB2	.5000	.5030	.9830	.4960	.4940	.5952
BFC1	.9900	1.0000	1.0000	.5120	.4570	.7918
BFC2	.4910	.7020	.9820	.4930	.4890	.6314
DBR	.5030	.5040	1.0000	.5000	.5060	.6026

Table 4. Process Utilization Rates

Meanwhile work stations that follow the constraint process were limited by the maximum number of units that could be processed by the constraint. If measured by utilization, the operators of these processes would be unfairly punished for consequences which were clearly beyond their control.

In general, inventory buffers help reduce the impact of variability on sequential processes and improve throughput. However, too much inventory in a system costs in terms of carrying cost, investment, and increased leadtimes to the customer. To reduce the amount of WIP allowed to accumulate in front of the constraint, the release of transactions into the system was subordinated to the constraint by tying raw material input to output of the constraint. Because the constraint output paced the system, the expected throughput was calculated by dividing the available time units by the constraint processing time (71.428). In the simulation of the Drum-buffer-rope system, actual output nearly equalled expected output. Even though the queues were unlimited and could grow infinitely, WIP did not build up in front of the constraint because work was not brought into the system until the system could process the work. Protective inventory in front of the constraint protected the constraint from the variability experienced by the processes in front of the constraint. Leadtime was reduced to the lowest level of any of the runs (Table 5). Unfortunately the utilization rate of the DBR model was lower than those same measurements of the CB1 and BFC1 runs. If utilization rates are used as performance measures, managers would not get high marks even though the system is effectively producing the units--with minimum investment in inventory and minimum leadtime--required to meet customer demand.

RUN	B	DBR
Throughput	136.73	71.36
WIP	26.25	4.99
Flow Time	393.497	163.235
Utilization	.9630	.6030

Table 5. Comparison of Baseline and Drum-Buffer-Rope

Analysis. Ideally, changes to the process should produce increased throughput, decreased inventory and decreased operating expense. These effects can be translated into positive changes in an organization's cash flow, net profit and return on investment performance measures. Appropriately placed buffers lessen the effects of statistical fluctuations and interdependent processes. In contrast, an unrestricted release of inventory into the system increases throughput at great expense--increased WIP inventory and total process flow time (leadtime) increasing inventory costs, operating expenses, and lengthening the logistics pipeline. These changes negatively impact an organization's cash flow, net profit and return on investment measures. The BUFFERED BASELINE models represent a Kanban system, a pull system created to limit queues and protect the system from disruptions.

Another way to improve system performance is to reduce the variability within the system. By decreasing processing variability, statistical fluctuations and process interdependence are reduced. Inventory levels and flow times are reduced while throughput is increased. Determining and eliminating the causes of variability may not be easily accomplished as evidenced by the Japanese experience. The magnitude of variability reductions may not be matched by corresponding increases in throughput. As variability approaches zero, the costs associated with variability reduction may exceed the benefits realized.

When the input rate was matched to the nonconstraints, the processes preceding the constraint processed inputs without regard to the capability of the constraint. WIP inventories built up in front of the constraint creating increased inventory costs and operating expenses. Throughput was limited by the constraint output rate. No matter how much the first two processes produced, the system was incapable of producing more than the constraint. The utilization rates of the processes following the constraint were directly related to the constraint output rate.

The Drum-Buffer-Rope model demonstrated that subordinating the system to the constraint provided the preferred relationship between throughput, inventory and operating expense. Raw materials were inducted at the same rate as the constraint processing rate. Limiting the amount of materials in the system reduces queue build ups and reduces flow times/leadtimes.

Analysis of system behavior in all of the runs demonstrated that utilization rates are by-products of the system, not performance measures. There is very little correlation between the average level of resource utilization and the measures of throughput, inventory, and operating expense. The simulation demonstrated that utilization rates of nonconstraints exceeding constraint capacities resulted in increased WIP levels and prolonged flow times.

Process Section

Capacity Concept and Definitions:

Finding. The clearest result of evaluating capacity and utilization measurement methods is the obvious lack of agreement on the definition of the terms. As stated in Chapter 1, many definitions are found in both the private sector and DOD. DoD 4151.15H requires three different capacity calculations: gross capacity, physical capacity, peacetime workloading capacity. A proposed DoD 4151.15H revision changes the concept of capacity and utilization. Capacity and utilization are now computed as indexes and considered as general indicators rather than precise measures. Additionally, capacity is broken down into productive, reserve, and excess capacity.

Analysis. Defining the concepts of capacity and utilization in the DOD depots is nebulous. Lack of concise and commonly accepted definitions within DOD, industry, and Congress contribute to the inability of the different communities to effectively communicate among and within themselves.

<u>Approaches to Capacity and Utilization</u>:

<u>Finding</u>. The many definitions of capacity and utilization can be divided into two broad approaches, engineering and economic. The engineering approach states that capacity is the maximum output a plant can produce with the equipment and facilities available. An engineering approach is valid when the focus is on potential output and war mobilization. An economic approach adopts a cost orientation or business management perspective. The economic approach defines capacity as that level of output where average total cost is the lowest. (reference) Although the economic approach to measuring capacity and utilization appears in the literature, its application appears to be limited to theory and research.

These same concepts apply to utilization measurements. The engineering approach paints a picture of the actual output compared to the potential output while the economic approach is tied to cost curves. A survey of commercial firms conducted by Logistics Management Institute for the Joint Policy Coordinating Group on Depot Maintenance determined that of the seven firms surveyed, only one computed utilization. The remaining firms have not institutionalized utilization computation although utilization is assumed to be small in overall planning. In these firms utilization is not considered in strategic planning nor is it used as a performance measurement (Joint Policy..., 1990).

DOD has taken an engineering approach to capacity measurement and capacity utilization. Policy directives and instructions have focused on work positions and equipment availability factors to determine potential output. Utilization computation has also been required although no agency has issued specific instructions concerning computation methodology. Both measurements are calculated in terms of Direct Labor Hours as opposed to throughput. Proposed DoD 4151.15H revisions providing instructions for computing capacity and utilization indexes are now being used by the services (Figure 5). The capacity index replaces the peacetime workloading capacity computation while the physical capacity index replaces the former physical capacity figure. To ensure comparability among the services, these standard factors are provided:

Annual Paid Hours, 2080;

Annual Productive Hours, 1615;

Availability, 0.95.

The revised computation methodology reflects a change in philosophy, a shift recognizing the degradation of specificity as capacity measures are aggregated (Joint Policy...,1990). The capacity index indicates the amount of workload that a facility can effectively produce annually on a single shift, 40-hour week basis while producing the product mix that the facility is designed to accommodate. The formula for computing the capacity index is:

(work positions)x(availability factor)x(annual productive hours)

The <u>physical capacity index</u> indicates the amount of workload that a facility can accommodate with all work positions continuously manned on a single shift, 40-hour week basis, while producing the product mix that the facility is designed to accommodate. The physical capacity index is used for mobilization planning purposes and assumes that work positions will be continuously manned and that all holidays will be worked. The formula for computing the physical capacity index is:

(work positions)x(availability factor)x(annual paid hours)

Shop level capacity indexes are summed to obtain the total depot capacity index.

Capacity not being used is separated into two categories, reserve and excess. As described in the proposed revised DoD 4151.15H, <u>reserve capacity</u> may be retained for reasons of military necessity or sound business practice. This capacity category must be separately identified and justified. <u>Excess capacity</u> need only be identified by shop and direct labor hours at the depot level. Specific rationale for determining and maintaining reserve and excess capacity are to be developed by each service component of the DOD.

The proposed DoD 4151.15H derives utilization measurement

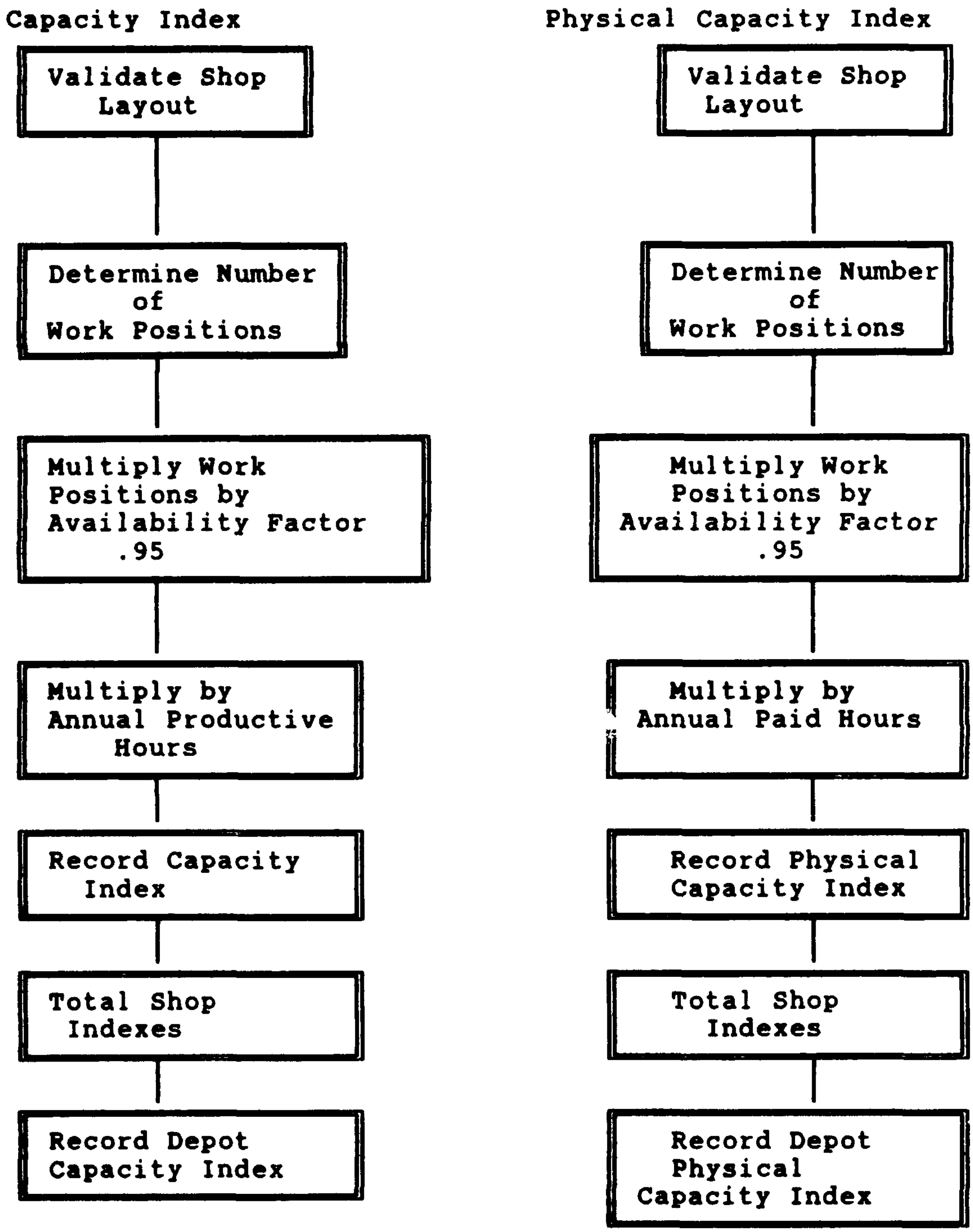

Figure 5. Capacity Computation Flow Chart

from the basic formula:

$$\frac{\text{(workload)}}{\text{(Capacity Index)}}$$

Specific utilization indexes defined by specific workload and/or capacity indexes are:

$$\underline{\text{Peacetime Utilization Index}} = \frac{\text{Funded Workload}}{\text{Capacity Index}}$$

$$\underline{\text{Mission Utilization Index}} = \frac{\text{Executable Requirements}}{\text{Capacity Index}}$$

$$\underline{\text{Mobilization Utilization Index}} = \frac{\text{Mobilization Requirements}}{\text{Physical Capacity Index}}$$

To compute the prior year capacity index, funded workload is the actual workload performed in the prior year. The current year capacity index is computed by using the estimated current year workload to represent funded workload. The forecasted workload in the Six Year Defense Plan at the time of the Service Program Objective Memorandum submission represents the funded workload used to calculate the capacity index for future years. Executable requirements are requirements that could be executed if funds were available. Mobilization requirements are those requirements that would generate in the event of a given mobilization scenario, such as Desert Shield/Storm.
The capacity and utilization indexes provide information about the relative size of depots but not specific data relative to performance (Joint..,1990).

<u>Analysis</u>. Aggregated capacity and utilization data developed within DOD are currently used as performance

measures by Congress. The data is evaluated in terms of the overall goal of DOD and the individual services. The measurement methodology used by the services to determine the capacity index provides an inflated value since reserve capacity is not considered a valid reason for maintaining capability. However, by definition, once reserve capacity is established, it should not be included in determining available capacity unless requirements change. By including reserve capacity in the capacity index, the utilization indexes computed are understated. The current methodology results in a distorted snapshot of depot capabilities. Resource allocation planning is thus negatively impacted.

Goldratt's Theory of Constraints (1990) states that utilization data is a by-product of the production process and should not be considered a performance measurement. Further, utilization is not synonymous with activation, which he considers to be the turning on of equipment. In contrast, utilization is defined as the operating time devoted to transforming inventory into throughput. Under the Theory of Constraints, constraint management becomes the system driver. Capacity is relevant only in terms of the constrained resources relative to the market demand.

The critical aspect of constraint management is identification of the constraint and the subsequent resource planning to protect the constraint from statistical fluctuations and flow disruptions. Raw materials should enter the system based on the capacity or production rate of the constraint. In this way, inventory levels would be minimized, lead times would be reduced, and operating expenses would also decrease. The reduced lead times would increase the organization's competitive edge. The improvements realized through effective constraint management can be translated into increases in net profit, return on investment, and cash flow.

V. Limitations, Conclusions, and Recommendations

This chapter addresses the limitations of this research project and the conclusions drawn from the research results. This chapter concludes with recommendations for further research developed from the conclusions.

Limitations

The capacity/utilization model was tailored to offset the common storage limitations of GPSSH. The values of the mean and spread of the generation rate and the processing times were selected to ensure that the number of transactions created would not exceed the 40K bytes limit of common storage available.

Conclusions

The principal conclusion drawn from the simulation results is that utilization rates are by-products of the process. When a constraint exists in a system--and all systems have constraints--there is little relationship between the average utilization rate for a system and the expected output of the system.

Unfortunately setting a goal of high utilization of interdependent resources exacts a high price in leadtime and WIP inventories. Utilization rates do not reflect process effectiveness nor do they provide information on the level of customer satisfaction achieved. Although there exists the need to know how many resources/facilities are available to perform a given volume of work, the effectiveness of the resource usage is better measured in whether or not the resources are being used to satisfy customer needs. The questions asked should be whether or not demand is being satisfied (throughput) and how efficiently is that demand satisfaction being accomplished. Levels of work in process inventory, leadtimes, and operating expenses are measure to be used in making decisions about the effectiveness of an organization.

One conclusion drawn from the process research is that specific and explicit terminology must be used to ensure effective communication among the various data users. Utilization is not synonymous with effectiveness.

Improved requirements forecasting techniques must be developed to reduce the impact of changing requirements on resource utilization planning. The Japanese have demonstrated that the most powerful approach to improving forecast accuracy is the reduction of lead time. The shorter the required planning horizon the more accurate the forecast--this axiom applies to any environment. The uniqueness of the depot maintenance arena must be considered and factored into the decision-making process.

While the private sector business motive of profit is not available to the depot maintenance manager, parallels can be drawn. The depots, while not tasked with being profitable, do have the responsibility to attempt not to lose money. The generation of "surplus" revenue could be reallocated or rebated to the customer to the benefit of all parties. This however would require substantial changes in the financial management system used in the DOD.

The use of direct labor hours as a measurement of capacity does not provide meaningful information when those numbers are aggregated without regard to the type of work accomplished.

Recommendations

Utilization rates should not be used as performance indicators. While correlated to total output, high utilization can also lead to counterproductive behavior for nearly every functional area of the system. In contrast, customer satisfaction (throughput should be matched with customer demand) and process efficiency (inventory and operating expense) should be the criteria used. Utilization rates are valid measure to be used in the planning process to determine an organization's ability to meet customer demand. The services should jointly develop and establish performance measures based on throughput, inventory and operating expense to be used to evaluate process effectiveness.

DOD policy should address effectiveness, not utilization. Resource effectiveness measures should factor out reserve and excess capacity. A depot-level computer model should be developed to permit the services to track peacetime and war mobilization requirements, resource capacities, demand, throughput, inventory, and operating expense, and the availability status of the resources. The model should be interactive and provide a hands on "what if" capability.

Appendix A: Capacity Utilization Simulation Model Inputs

RUN TYPE	BASE	VAR 1	VAR 2
RUN #	B	BV1	BV2
LIMITS	(5,30)	(10,25)	(15,20)
WEEKS	5	*	*
CAPACITIES			
RECV	1	*	*
DASM	1	*	*
REPR	1	*	*
ASSM	1	*	*
FINAL	1	*	*
GENERATE			
MEAN	17.5	*	*
SPREAD	12.5	*	*
PROCESS MEAN/SPREAD			
RECV	17.5/12.5	17.5/7.5	17.5/2.5
DASM	17.5/12.5	17.5/7.5	17.5/2.5
REPR	17.5/12.5	17.5/7.5	17.5/2.5
ASSM	17.5/12.5	17.5/7.5	17.5/2.5
FINAL	17.5/12.5	17.5/7.5	17.5/2.5
BUFFER CAPACITY			
RECV	N/A	*	*
DASM	N/A	*	*
REPR	N/A	*	*
ASSM	N/A	*	*
FINAL	N/A	*	*

* = baseline value

CAPACITY UTILIZATION SIMULATION MODEL INPUTS Continued

RUN TYPE	CONSTRAINED BASELINE		BUFFERED BASELINE		
RUN #	CB1	CB2	BB1	BB2	BB3
LIMITS	*	*	*	*	*
WEEKS	*	*	*	*	*
CAPACITIES					
RECV	*	2	*	*	*
DASM	*	2	*	*	*
REPR	*	*	*	*	*
ASSM	*	2	*	*	*
FINL	*	2	*	*	*
GENERATE					
MEAN	*	*	*	*	*
SPREAD	*	*	*	*	*
PROCESS MEAN/SPREAD					
RECV	*	*	*	*	*
DASM	*	*	*	*	*
REPR	35/12.5	*	*	*	*
ASSM	*	*	*	*	*
FINAL	*	*	*	*	*
BUFFER CAPACITY					
RECV	N/A	N/A	6	9	12
DASM	N/A	N/A	6	9	12
REPR	N/A	N/A	6	9	12
ASSM	N/A	N/A	6	9	12
FINAL	N/A	N/A	6	9	12

CAPACITY UTILIZATION SIMULATION MODEL INPUTS Continued

RUN TYPE	BUFFERED CONSTRAINED		DRUM-BUFFER-ROPE
RUN #	BFC1	BFC2	DBR
LIMITS	*	*	*
WEEKS	*	*	*
CAPACITIES			
RECV	*	2	*
DASM	*	2	*
REPR	*	*	*
ASSM	*	2	*
FINL	*	2	*
GENERATE			
MEAN	*	*	*
SPREAD	*	*	*
PROCESS MEAN/SPREAD			
RECV	*	*	*
DASM	*	*	*
REPR	35/12.5	17.5/12.5	35
ASSM	*	*	*
FINL	*	*	*
BUFFER CAPACITY			
REPR	6	6	6

Appendix B: Capacity Utilization Simulation Program Code

BASELINE CAPACITY/UTILIZATION SIMULATION

```
*----------------------------------------------------------
      SIMULATE

*     ampervariable declarations
      REAL &M(6),&S(6)
      INTEGER &SCAP(5),&WEEKS,&I,&J,&K

*     file declarations
 SPEC   FILEDEF 'mdlspec.dat'
 RSLT   FILEDEF 'mdlrslt.dat'

*     read input parameters
      GETLIST    FILE=SPEC,(&WEEKS,(&SCAP(&I),&I=1,5),(&M(&J),&S(&J),&J=1,6))
*     storage declaration
      STORAGE S(RECV),&SCAP(1)/S(DASM),&SCAP(2)
      STORAGE S(REPR),&SCAP(3)/S(ASSM),&SCAP(4)/S(FINL),&SCAP(5)
*----------------------------------------------------------
*     GPSS/H Block Section

      GENERATE   &M(1),&S(1)
      QUEUE      SYSQ
*     ADVANCE    0

*     receiving and check-in
      QUEUE      RECVQ
      ENTER      RECV
      DEPART     RECVQ
      ADVANCE    &M(2),&S(2)
      LEAVE      RECV

*     disassembly
      QUEUE      DASMQ
      ENTER      DASM
      DEPART     DASMQ
      ADVANCE    &M(3),&S(3)
      LEAVE      DASM

*     repair
      QUEUE      REPRQ
      ENTER      REPR
      DEPART     REPRQ
      ADVANCE    &M(4),&S(4)
      LEAVE      REPR

*     (re)assembly
      QUEUE      ASSMQ
      ENTER      ASSM
```

```
        DEPART    ASSMQ
        ADVANCE   &M(5),&S(5)
        LEAVE     ASSM

*       final parts check
        QUEUE     FINLQ
        ENTER     FINL
        DEPART    FINLQ
        ADVANCE   &M(6),&S(6)
        LEAVE     FINL

        DEPART    STSQ
 THRU   TERMINATE 0

*       sim. control xact (1500)
        GENERATE  100
        TERMINATE 1
*-----------------------------------------------------------
*       GPSS/H Control Statements
        DO        &K=1,30
        START     50
        RESET
        DO        &I=1,&WEEKS
        DO        &J=1,5
        START     1
        ENDDO
        ENDDO
        PUTPIC    FILE=RSLT,_
                  QA(RECVQ),SR(RECV)/1000,QA(DASMQ),SR(DASM)/1000,_
                  QA(REPRQ),SR(REPR)/1000,QA(ASSMQ),SR(ASSM)/1000,_
                  QA(FINLQ),SR(FINL)/1000,_
                  QT(STSQ),QA(STSQ),QM(STSQ),N(THRU)
 *.*** *.*** *.*** *.*** *.*** *.*** *.*** *.*** *.*** *.***  *.*** *.*** *.*** *.*** *.*** *.***    * *
*
        CLEAR
        ENDDO
        END

*-----------------------------------------------------------------
```

BUFFERED BASELINE CAPACITY/UTILIZATION SIMULATION MODEL

```
*----------------------------------------------------------------
        SIMULATE

*       supervariable declarations
        REAL &M(6),&S(6)
        INTEGER &SCAP(5),&WEEKS,&I,&J,&SBUF(5),&K,&D

*       file declarations
 SPEC     FILEDEF 'mdlspec.dat'
 RSLT     FILEDEF 'mdlrslt.dat'

*       read input parameters
        GETLIST    FILE=SPEC,(&WEEKS,(&SCAP(&I),&I=1,5),(&M(&J),&S(&J),&J=1,6),(&SBUF(&K),&K=1,5))

*       storage declaration
        STORAGE S(RECV),&SCAP(1)/S(DASM),&SCAP(2)
        STORAGE S(REPR),&SCAP(3)/S(ASSM),&SCAP(4)/S(FINL),&SCAP(5)
        STORAGE S(BUF1),&SBUF(1)/S(BUF2),&SBUF(2)
        STORAGE S(BUF3),&SBUF(3)/S(BUF4),&SBUF(4)/S(BUF5),&SBUF(5)
*----------------------------------------------------------------
*       GPSS/H Block Section

        GENERATE   &M(1),&S(1),0
        QUEUE      SYSQ
        ADVANCE    0
        ENTER      BUF1

*       receiving and check-in
        ENTER      RECV
        LEAVE      BUF1
        ADVANCE    &M(2),&S(2)
        ENTER      BUF2
        LEAVE      RECV

*       disassembly
        ENTER      DASM
        LEAVE      BUF2
        ADVANCE    &M(3),&S(3)
        ENTER      BUF3
        LEAVE      DASM

*       repair
        ENTER      REPR
        LEAVE      BUF3
        ADVANCE    &M(4),&S(4)
        ENTER      BUF4
        LEAVE      REPR

*       (re)assembly
        ENTER      ASSM
        LEAVE      BUF4
```

```
        ADVANCE   &M(5),&S(5)
        ENTER     BUF5
        LEAVE     ASSM

*       final parts check
        ENTER     FINL
        LEAVE     BUF5
        ADVANCE   &M(6),&S(6)
        LEAVE     FINL

        DEPART    SYSQ
 THRU   TERMINATE 0

*       sim. control set to run for 100 time units
        GENERATE  100
        TERMINATE 1
*---------------------------------------------------------------
*       GPSS/H Control Statements

        DO        &D=1,30
        START     50,NP
        RESET
        DO        &I=1,&WEEKS
        DO        &J=1,5
        START     1
        ENDDO
        ENDDO
        PUTPIC    FILE=RSLT,_
                  SA(BUF1),SR(RECV)/1000,SA(BUF2),SR(DASM)/1000,_
                  SA(BUF3),SR(REPR)/1000,SA(BUF4),SR(ASSM)/1000,SA(BUF5),SR(FINL)/1000,QT(SYSQ),QA(SYSQ),N(THRU)
*.*** *.*** *.*** *.*** *.*** *.*** *.*** *.*** *.*** *.*** *.*** *.*** *.***
        CLEAR
        ENDDO
        END

*---------------------------------------------------------------
```

BUFFERED CONSTRAINED CAPACITY/UTILIZATION SIMULATION MODEL

```
*--------------------------------------------------------------
         SIMULATE

*        supervariable declarations
         REAL &M(6),&S(6)
         INTEGER &SCAP(5),&WEEKS,&I,&J,&SBUF(1),&K,&D

*        file declarations
SPEC     FILEDEF 'mdlspec.dat'
RSLT     FILEDEF 'mdlrslt.dat'

*        read input parameters
         GETLIST    FILE=SPEC,(&WEEKS,(&SCAP(&I),&I=1,5),(&M(&J),&S(&J),&J=1,6),&SBUF(&K),&K=1,1)
*        storage declaration
         STORAGE S(RECV),&SCAP(1)/S(DASM),&SCAP(2)
         STORAGE S(REPR),&SCAP(3)/S(ASSM),&SCAP(4)/S(FINL),&SCAP(5)
         STORAGE S(BUF3),&SBUF(1)
*--------------------------------------------------------------
*        GPSS/H Block Section

         GENERATE    &M(1),&S(1)
         QUEUE       SYSQ
*        ADVANCE     0

*        receiving and check-in
         QUEUE       RECVQ
         ENTER       RECV
         DEPART      RECVQ
         ADVANCE     &M(2),&S(2)

*        disassembly
         QUEUE       DASMQ
         LEAVE       RECV
         ENTER       DASM
         DEPART      DASMQ
         ADVANCE     &M(3),&S(3)

*        repair
BUF3     ENTER       BUF3
         LEAVE       DASM
         ENTER       REPR
         LEAVE       BUF3
         ADVANCE     &M(4),&S(4)

*        (re)assembly
         QUEUE       ASSMQ
         LEAVE       REPR
         ENTER       ASSM
         DEPART      ASSMQ
         ADVANCE     &M(5),&S(5)
```

```
*      final parts check
       QUEUE       FINLQ
       LEAVE       ASSM
       ENTER       FINL
       DEPART      FINLQ
       ADVANCE     &M(6),&S(6)
       LEAVE       FINL

       DEPART      STSQ
 THRU  TERMINATE 0

*      sim. control xact (1500)
       GENERATE    100
       TERMINATE   1
*------------------------------------------------------------
*      GPSS/H Control Statements
       DO          &D=1,30
       START       50
       RESET
       DO          &I=1,&WEEKS
       DO          &J=1,5
       START       1
       ENDDO
       ENDDO
       PUTPIC      FILE=RSLT,_
                   QA(RECVQ),SR(RECV)/1000,QA(DASMQ),SR(DASM)/1000,_
                   SA(BUF3),SR(REPR)/1000,QA(ASSMQ),SR(ASSM)/1000,_
                   QA(FINLQ),SR(FINL)/1000,_
                   QT(STSQ),QA(STSQ),QM(STSQ),N(THRU)
 *.*** *.*** *.*** *.*** *.*** *.*** *.*** *.*** *.*** *.***  *.*** *.*** *.*** *.*** *.*** *.***
       CLEAR
       ENDDO
       END
```

DRUM-BUFFER-ROPE CAPACITY/UTILIZATION SIMULATION MODEL

```
*---------------------------------------------------------------
      SIMULATE

*     ampervariable declarations
      REAL &M(6),&S(6)
      INTEGER &SCAP(5),&WEEKS,&I,&J,&X,&SBUF(1),&K,&D
      INITIAL  LS(DRUM)

*     file declarations
 SPEC   FILEDEF 'mdlspec.dat'
 RSLT   FILEDEF 'mdlrslt.dat'

*     read input parameters
      GETLIST    FILE=SPEC,(&WEEKS,(&SCAP(&I),&I=1,5),(&M(&J),&S(&J),&J=1,6),&SBUF(&K),&K=1,1)
*     storage declaration
      STORAGE S(RECV),&SCAP(1)/S(DASM),&SCAP(2)
      STORAGE S(REPR),&SCAP(3)/S(ASSM),&SCAP(4)/S(FINL),&SCAP(5)
      STORAGE S(BUF3),&SBUF(1)
*---------------------------------------------------------------
*     GPSS/H Block Section

      GENERATE   ,,,1
      QUEUE      SYSQ
      TRANSFER   ,RECVQ

      GENERATE   ,,,1
      QUEUE      SYSQ
      TRANSFER   ,RECVQ

      GENERATE   ,,,1
      QUEUE      SYSQ
      TRANSFER   ,RECVQ

      GENERATE   &M(1),&S(1),0
      GATE LR    DRUM
      BLET       &X=&X+1
      TEST E     &X,1,RECV
      LOGIC S    DRUM
      BLET       &X=0
      QUEUE      SYSQ

*     receiving and check-in
RECVQ QUEUE      RECVQ
 RECV ENTER      RECV
      DEPART     RECVQ
      ADVANCE    &M(2),&S(2)
      LEAVE      RECV

*     disassembly
 DASMQ QUEUE     DASMQ
      ENTER      DASM
```

```
        DEPART     DASMQ
        ADVANCE    &M(3),&S(3)
   BUF3 ENTER      BUF3
        LEAVE      DASM

*       repair
   REPR ENTER      REPR
        LEAVE      BUF3
        ADVANCE    &M(4),&S(4)
        LEAVE      REPR
        TEST LE    Q(REPRQ),1,NXT
        LOGIC R    DRUM

*       (re)assembly
    NXT QUEUE      ASSMQ
        ENTER      ASSM
        DEPART     ASSMQ
        ADVANCE    &M(5),&S(5)
        LEAVE      ASSM

*       final parts check
        QUEUE      FINLQ
        ENTER      FINL
        DEPART     FINLQ
        ADVANCE    &M(6),&S(6)
        LEAVE      FINL

        DEPART     SYSQ
  THRU  TERMINATE 0

*       sim. control xact (1500)
        GENERATE   100
        TERMINATE  1
*----------------------------------------------------------------
*       GPSS/H Control Statements

        DO         &D=1,30
        START      50,
        RESET
        DO         &I=1,&WEEKS
        DO         &J=1,5
        START      1
        ENDDO
        ENDDO
        PUTPIC     FILE=RSLT,_
                   QA(RECVQ),SR(RECV)/1000,QA(DASMQ),SR(DASM)/1000,_
                   SA(BUF3),SR(REPR)/1000,QA(ASSMQ),SR(ASSM)/1000,_
                   QA(FINLQ),SR(FINL)/1000,_
                   QT(SYSQ),QA(SYSQ),QM(SYSQ),N(THRU)
*.*** *.*** *.*** *.*** *.*** *.*** *.*** *.*** *.*** *.*** *.*** *.*** *.*** *.***
        CLEAR
        ENDDO
        END
```

Appendix C: Simulation Model Result Summary

CAPACITY/UTILIZATION SIMULATION RESULTS SUMMARY												
						UTILIZATION RATES					
RUN #	AVG UTE	AVG SYS WIP	EXPECTED THRUPUT	ACTUAL THRUPUT	FLOW TIME	RECV	DASM	REPR	ASSM	FINL	AVG
B	0.963	26.253	142.850	136.070	393.497	0.9800	0.9660	0.9580	0.9650	0.9450	0.9628
BB1	0.975	30.357	142.850	136.730	440.938	0.9980	0.9830	0.9730	0.9680	0.9540	0.9752
BB2	0.973	28.489	142.850	137.070	420.208	0.9960	0.9840	0.9670	0.9670	0.9500	0.9728
BB3	0.974	29.623	142.850	137.470	427.445	0.9890	0.9850	0.9730	0.9610	0.9620	0.9740
BV1	0.983	19.086	142.850	138.600	296.955	0.9940	0.9860	0.9750	0.9810	0.9790	0.9830
BV2	0.995	10.193	142.850	141.700	167.015	0.9970	0.9980	0.9950	0.9940	0.9920	0.9952
CB1	0.793	180.306	71.400	71.970	1568.680	0.9920	0.9750	1.0000	0.4980	0.5010	0.7932
CB2	0.595	11.512	142.850	140.270	186.459	0.5000	0.5030	0.9830	0.4960	0.4940	0.5952
BFC1	0.792	176.123	71.400	71.740	1566.992	0.9900	1.0000	1.0000	0.5120	0.4570	0.7918
BFC2	0.631	7.176	142.850	139.700	199.306	0.4910	0.7020	0.9820	0.4930	0.4890	0.6314
DBR	0.603	4.991	71.400	71.360	163.235	0.5030	0.5040	1.0000	0.5000	0.5060	0.6026

Table 6. Summarized Capacity/Utilization Simulation Results

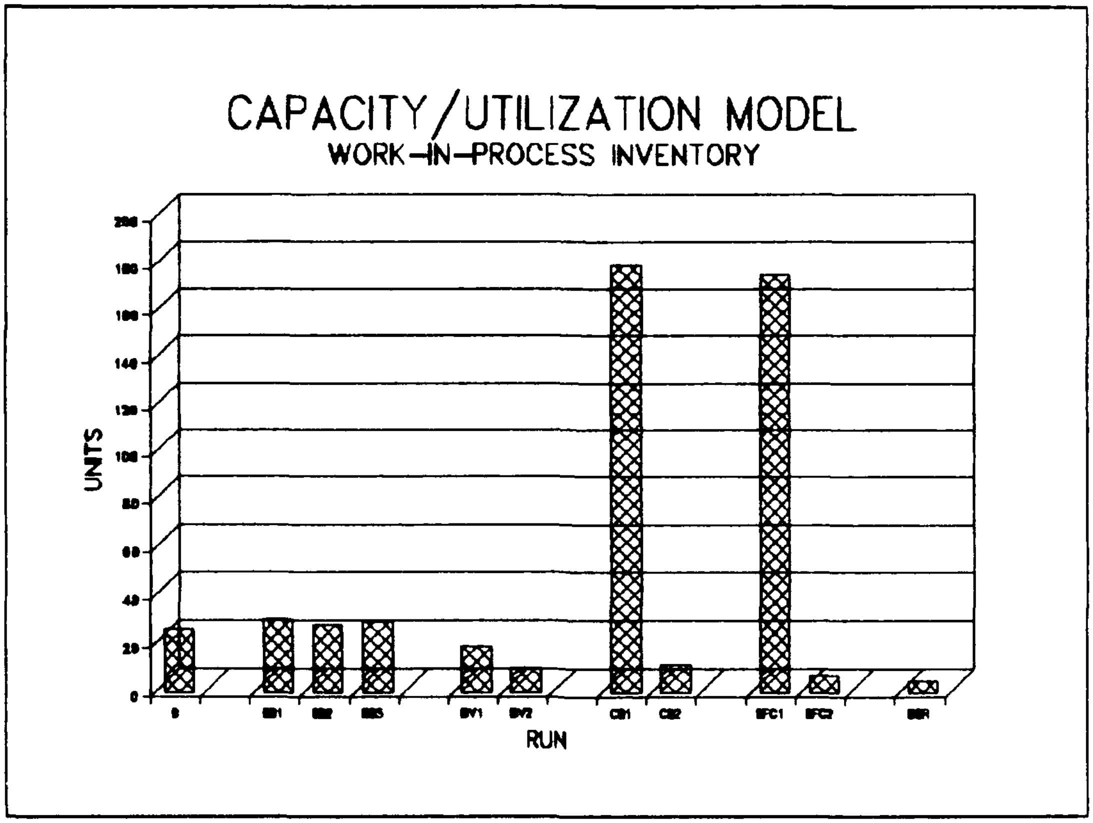

Figure 6. Work In Process & Inventory Comparison

RUN	RUN TYPE	UTILIZATION RATE
B	Baseline	0.9628
BB1	Buffered Baseline (Buffer 6)	0.9752
BB2	Buffered Baseline (Buffer 9)	0.9728
BB3	Buffered Baseline (Buffer 12)	0.9740
BV1	Reduced Variability (7.5 spread)	0.9830
BV2	Reduced Variability (2.5) spread	0.9952
CB1	Constrained Baseline(REPR mean 35)	0.7932
CB2	Constrained Baseline(NC capacity 2)	0.5952
BFC1	Buffered Constrained (Buffer 6, C1)	0.7918
BFC2	Buffered Constrained (Buffer 6, C2)	0.6314
DBR	Drum-Buffer-Rope (Buffer 6)	0.6026

NC = Non-constraint
C1 = CB1
C2 = CB2

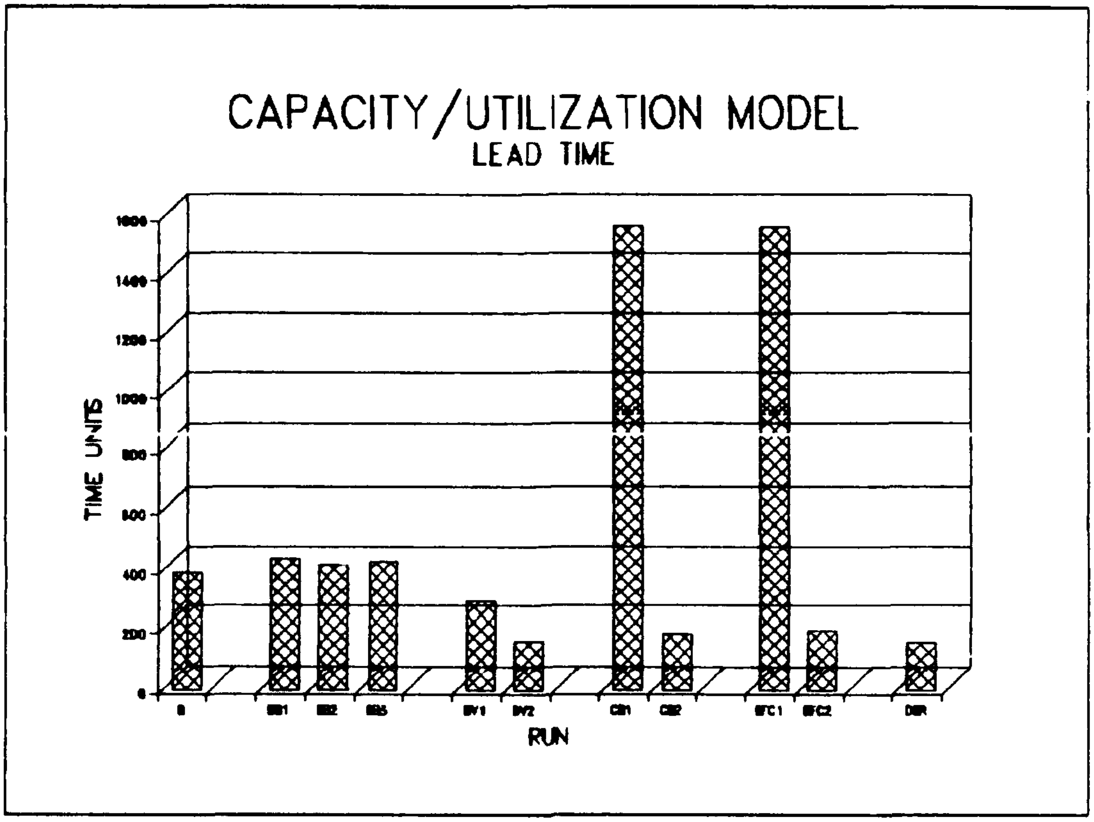

Figure 7. Capacity Utilization Model Lead Times

RUN	RUN TYPE	UTILIZATION RATE
B	Baseline	0.9628
BB1	Buffered Baseline (Buffer 6)	0.9752
BB2	Buffered Baseline (Buffer 9)	0.9728
BB3	Buffered Baseline (Buffer 12)	0.9740
BV1	Reduced Variability (7.5 spread)	0.9830
BV2	Reduced Variability (2.5) spread	0.9952
CB1	Constrained Baseline(REPR mean 35)	0.7932
CB2	Constrained Baseline(NC capacity 2)	0.5952
BFC1	Buffered Constrained (Buffer 6, C1)	0.7918
BFC2	Buffered Constrained (Buffer 6, C2)	0.6314
DBR	Drum-Buffer-Rope (Buffer 6)	0.6026

NC = Non-constraint
C1 = CB1
C2 = CB2

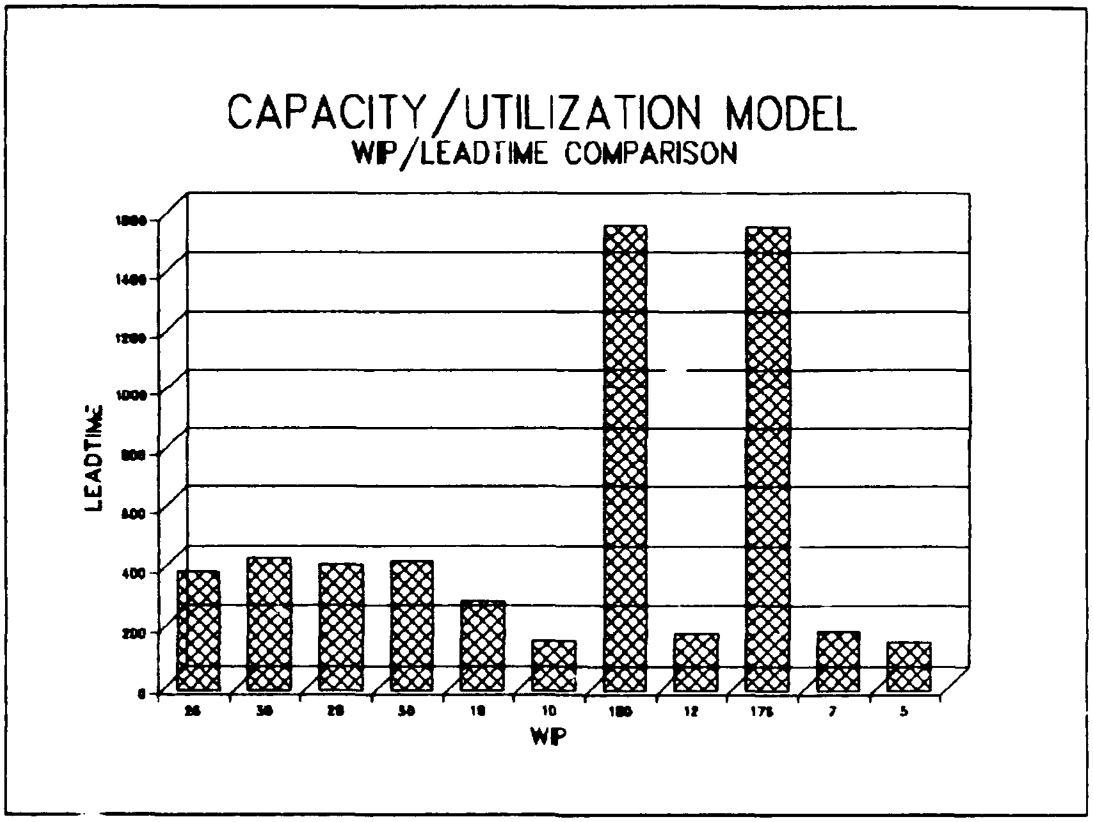

Figure 8. WIP & Leadtime Comparison

RUN	RUN TYPE	UTILIZATION RATE
B	Baseline	0.9628
BB1	Buffered Baseline (Buffer 6)	0.9752
BB2	Buffered Baseline (Buffer 9)	0.9728
BB3	Buffered Baseline (Buffer 12)	0.9740
BV1	Reduced Variability (7.5 spread)	0.9830
BV2	Reduced Variability (2.5) spread	0.9952
CB1	Constrained Baseline(REPR mean 35)	0.7932
CB2	Constrained Baseline(NC capacity 2)	0.5952
BFC1	Buffered Constrained (Buffer 6, C1)	0.7918
BFC2	Buffered Constrained (Buffer 6, C2)	0.6314
DBR	Drum-Buffer-Rope (Buffer 6)	0.6026

NC = Non-constraint
C1 = CB1
C2 = CB2

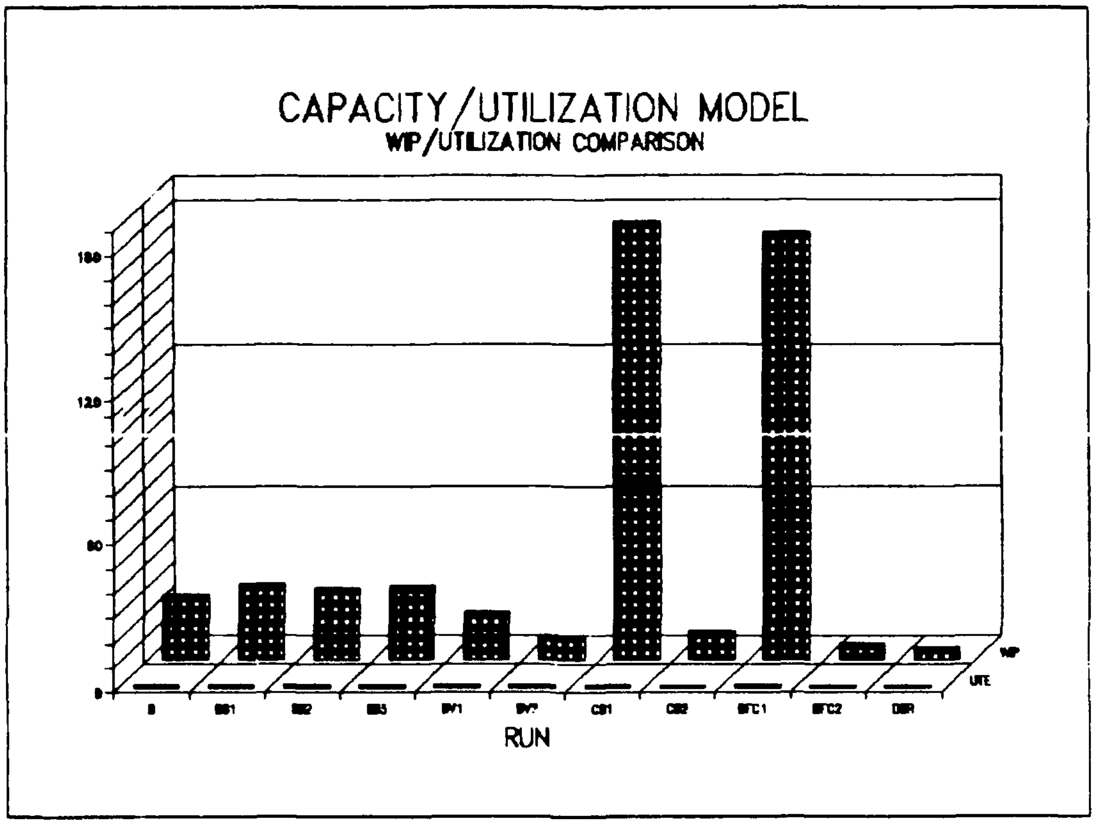

Figure 9. WIP & Utilization Comparison

RUN	RUN TYPE	UTILIZATION RATE
B	Baseline	0.9628
BB1	Buffered Baseline (Buffer 6)	0.9752
BB2	Buffered Baseline (Buffer 9)	0.9728
BB3	Buffered Baseline (Buffer 12)	0.9740
BV1	Reduced Variability (7.5 spread)	0.9830
BV2	Reduced Variability (2.5) spread	0.9952
CB1	Constrained Baseline(REPR mean 35)	0.7932
CB2	Constrained Baseline(NC capacity 2)	0.5952
BFC1	Buffered Constrained (Buffer 6, C1)	0.7918
BFC2	Buffered Constrained (Buffer 6, C2)	0.6314
DBR	Drum-Buffer-Rope (Buffer 6)	0.6026

NC = Non-constraint
C1 = CB1
C2 = CB2

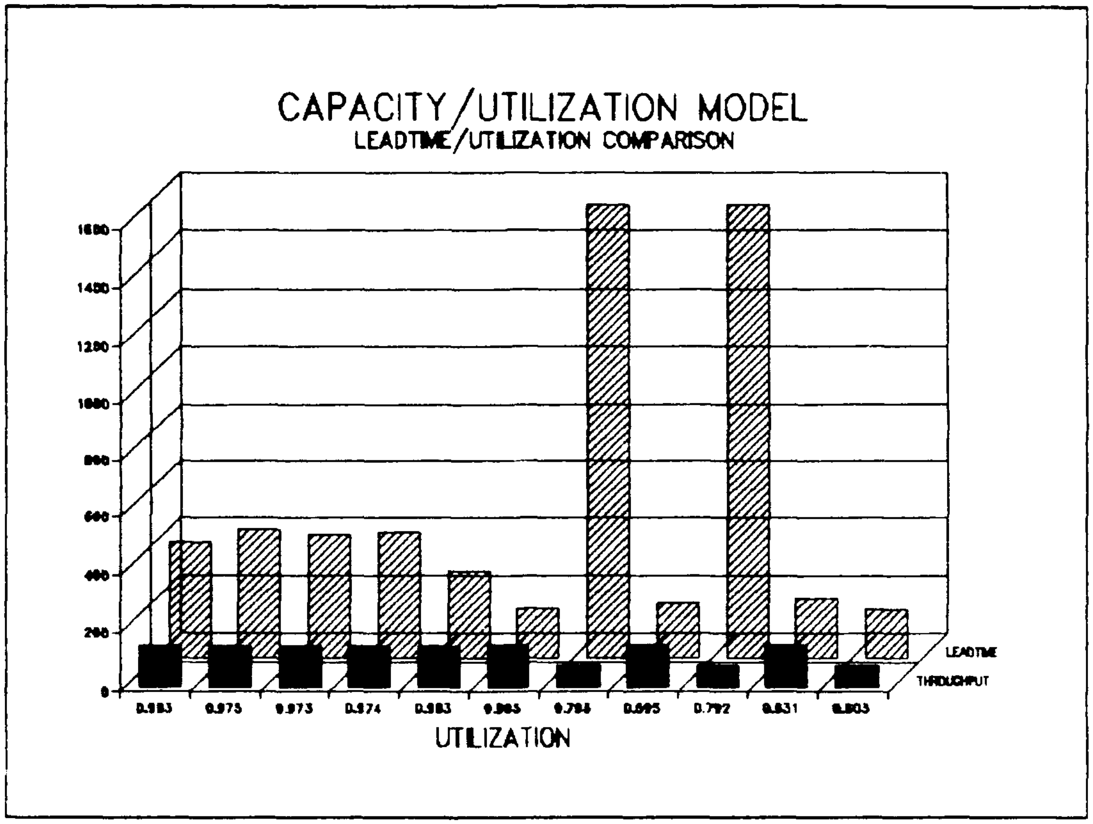

Figure 10. Leadtime/Utilization Comparison

RUN	RUN TYPE		UTILIZATION RATE
B	Baseline		0.9628
BB1	Buffered Baseline	(Buffer 6)	0.9752
BB2	Buffered Baseline	(Buffer 9)	0.9728
BB3	Buffered Baseline	(Buffer 12)	0.9740
BV1	Reduced Variability	(7.5 spread)	0.9830
BV2	Reduced Variability	(2.5) spread	0.9952
CB1	Constrained Baseline	(REPR mean 35)	0.7932
CB2	Constrained Baseline	(NC capacity 2)	0.5952
BFC1	Buffered Constrained	(Buffer 6, C1)	0.7918
BFC2	Buffered Constrained	(Buffer 6, C2)	0.6314
DBR	Drum-Buffer-Rope	(Buffer 6)	0.6026

NC = Non-constraint
C1 = CB1
C2 = CB2

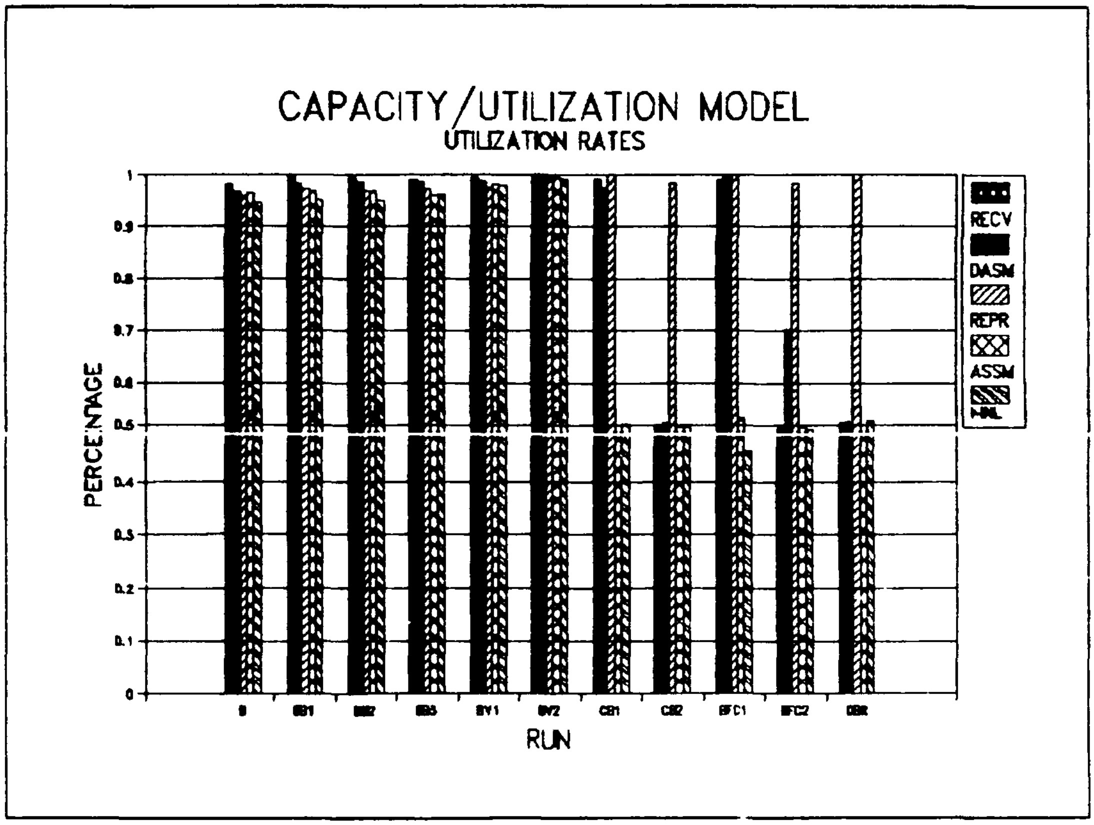

Figure 11. Utilization Rates

RUN	RUN TYPE	UTILIZATION RATE
B	Baseline	0.9628
BB1	Buffered Baseline (Buffer 6)	0.9752
BB2	Buffered Baseline (Buffer 9)	0.9728
BB3	Buffered Baseline (Buffer 12)	0.9740
BV1	Reduced Variability (7.5 spread)	0.9830
BV2	Reduced Variability (2.5) spread	0.9952
CB1	Constrained Baseline(REPR mean 35)	0.7932
CB2	Constrained Baseline(NC capacity 2)	0.5952
BFC1	Buffered Constrained (Buffer 6, C1)	0.7918
BFC2	Buffered Constrained (Buffer 6, C2)	0.6314
DBR	Drum-Buffer-Rope (Buffer 6)	0.6026

NC = Non-constraint
C1 = CB1
C2 = CB2

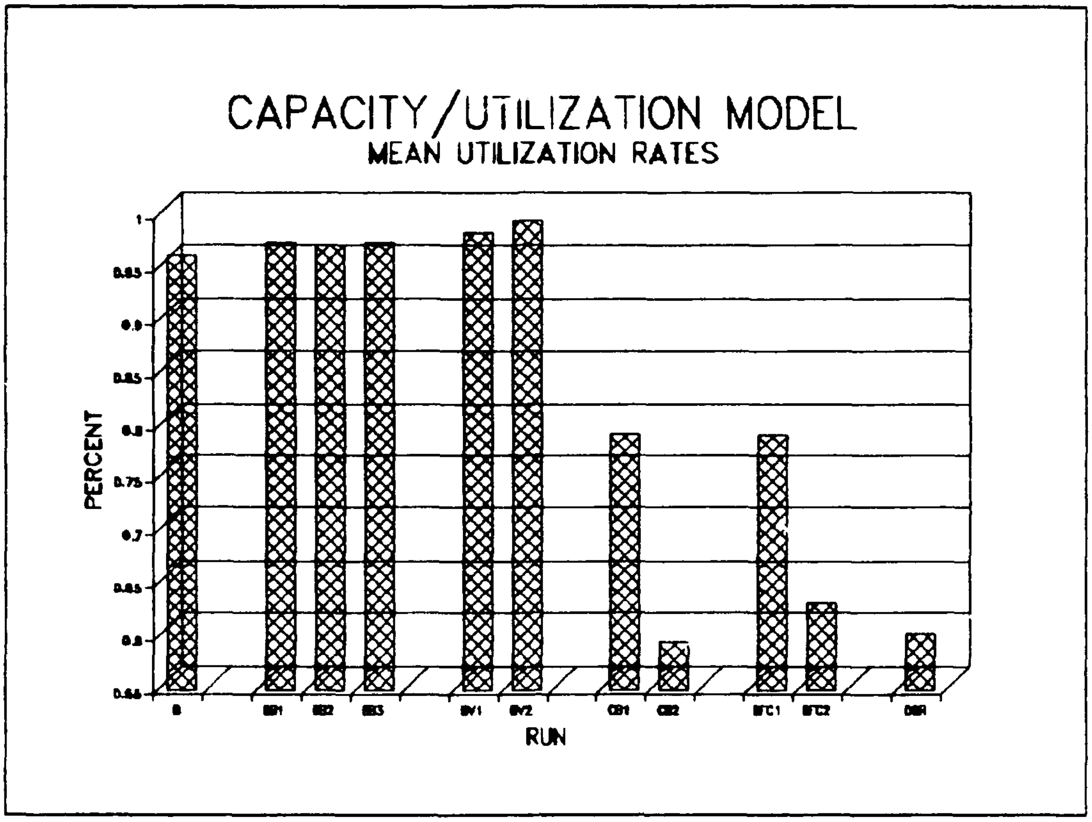

Figure 12. Mean Utilization Rates

RUN	RUN TYPE	UTILIZATION RATE
B	Baseline	0.9628
BB1	Buffered Baseline (Buffer 6)	0.9752
BB2	Buffered Baseline (Buffer 9)	0.9728
BB3	Buffered Baseline (Buffer 12)	0.9740
BV1	Reduced Variability (7.5 spread)	0.9830
BV2	Reduced Variability (2.5) spread	0.9952
CB1	Constrained Baseline(REPR mean 35)	0.7932
CB2	Constrained Baseline(NC capacity 2)	0.5952
BFC1	Buffered Constrained (Buffer 6, C1)	0.7918
BFC2	Buffered Constrained (Buffer 6, C2)	0.6314
DBR	Drum-Buffer-Rope (Buffer 6)	0.6026

NC = Non-constraint
C1 = CB1
C2 = CB2

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13. ABSTRACT (Maximum 200 words) This study investigated the effects of mandated depot capacity utilization rates on throughput, inventory, and operating expense. The measures of merit analyzed were work in process inventories, leadtime, and throughput. Since the services do not use a common computer system to track/compute capacity data, a computer simulation provided the data used to meet the research objectives. The simulation modeled a serially interdependent system subject to statistical fluctuations. Variability in the system was reduced by reducing the spread around the processing time mean. Buffer inventories were placed in front of each process to protect the process from variability. Constrained systems were buffered and the results analyzed. It was concluded that utilization rates do not reflect process effectiveness nor do they provide information on the level of customer satisfaction achieved. Additionally, this study resulted in the recommendation that DOD policy address effectiveness, not utilization and that performance measures based on throughput, inventory, and operating expense be used to evaluate process effectiveness.

14. SUBJECT TERMS	15. NUMBER OF PAGES
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5. Comments

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